Locating Electric Vehicle Charging Stations in Istanbul with AHP Based Mathematical Modelling

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Abstract: - In recent years, because of the soaring prices of oil and the environmental issues, automakers have offered electric vehicles for sustainable transportation. However, the transition to EVs is currently facing various shortcomings among which are: the high cost of EV batteries and their limited driving range, and underdeveloped charging station infrastructure. To overcome these shortcomings, it is significant to install sufficient charging station to the critical sites. In this paper, we address the problem of where to locate charging stations in districts of Istanbul, Turkey. The problem of where to locate electric vehicle charging station can be grouped as a decision making problem while many criteria and alternatives have to be considered simultaneously. Therefore, ten alternative locations are identified in Kadıkoy and Atasehir, two districts of Istanbul. Three main criteria are formed from the literature review to compare these alternative locations with each other. Analytic Hierarchy Process (AHP) methodology is used to obtain composite weight of each alternative locations and to rank them. Then these weights are used as input for mathematical model to determine the number of charging station to install. The mathematical model is formulated to maximize the user utility under budget and capacity constraints to obtain optimal number of charging station for each alternative point. Therefore, the composite weights used in mathematical model affect the number of charging stations to locate. Finally, the integrating methodology yields effective and robust results.

Key-Words: - Electric vehicle charging station, AHP, Mathematical modelling, Location selection

1 Introduction

Nowadays, the transportation sector depends on liquid fossil fuel derived from crude oil for 95%, which implies that 50% of the crude oil production is used only for transportation. In this contest, road vehicles based on full electric or hybrid drives attract great attention as a good solution to solve the problems of liquid fossil fuel dependence [1]. Over the last years with increasing environmental consciousness, the use of electric vehicles (EVs) has become critical due to the economic and environmental importance for an effective and an energy-efficient urban freight distribution [2].

The advancement of EVs in developing countries is moderate because the existing infrastructure is inadequate and the needed infrastructure to install is expensive. Turkey is one of these countries that EV technology develops slowly. The first EVs were sold in Turkey in 2012. According to the statement made by Turkey Electric Vehicle and Hybrid Vehicles Association 23 electric and hybrid vehicles were sold in Turkey during the first three months of 2016, while the number increased to 563 in the same period of 2017. As the number of electric vehicles on the road increases, the increase is expected in the demand for charging stations. If adequate charging infrastructure is made available, the adaption of drivers to this technology may increase through reducing electric vehicle owners' current anxieties over the mileage range [3].

There are three primary types of electric vehicle supply equipment (EVSE) which are Level 1, Level 2, and direct current (DC) fast charging station. Level 1 and Level 2 supply alternating current (AC) to the vehicle, which the vehicle's onboard charging equipment converts to DC needed to charge the batteries. DC fast charging stations supply DC electricity directly to the vehicle's battery. The differences in supply power and charging time for Level 1, Level 2, and DC fast charging are illustrated in Table 1.

Table 1. Supply powers and charging times

Charging Level	Supply Power	Charging Time
Level 1	220 – 240V/16A	6 – 8 hours
Level 2	380V/16A	2 – 4 hours
DC Fast Charging	380V/32A	30 minutes – 1 hour

In this study, we are focusing on Level 2 charging stations because Level 2 charging stations are perfect for times when people are parked for about two or three hours, such as at shopping malls, restaurants or sporting events. It will be less costly to place charging stations in these locations that already have the infrastructure to provide electrical service. Besides, Level 2 EVSE necessitates less maintenance and repair because of its modular design which minimizes the costs in case of malfunction.

The remainder of this study is structured as follows. Section 2 reviews the literature related to electric vehicle charging (EVCS) stations in terms of EVCS site determination and then defines the main contributions of this paper. In Section 3 the proposed methodology is presented. Section 4 presents implementation. Firstly, background information of the case study area is provided. Alternative locations are identified for the sitting of charging stations. The decision criteria of the charging station site selection are presented and evaluated. The weights of each criterion are calculated by using AHP. The optimal number of charging stations is obtained by using mathematical model with the given budget. In the last section (Section 5), the conclusion is provided.

2 Literature Review

In the literature, there are some articles related to electric vehicle charging station location problem. Ying-Wei Wang used integer program to determine the optimal locations of electric vehicles' recharging stations and applied it to Penghu, Taiwan [4]. Meng and Kai proposed game theory to optimize the electric vehicle charging station location. The game model was transformed into linear programming model and solved by primal-dual path following algorithm [5]. Jia et al. presented an optimization model to find the feasible site and size of electric vehicle charging stations. The aim of the model is to minimize both cost of charging stations and customers. The model was applied to Stockholm, Sweden and was solved by Cplex [6]. Chen et al. built a mixed integer programming model to find the optimal location and number of electric vehicle charging stations in Seattle [7]. Shi and Lee formulated a multi-objective mathematical model to obtain an effective result for the electric vehicle charging station model. It is aimed to minimize the charging stations' and customers' costs and maximize charging poles' utility [8]. Shahraki et al. presented an optimization model which considers public charging demand and applied it to Beijing, China. They aimed to maximize the electric vehicle use, therefore, used the model to find optimal location of charging station. The objective function of the model minimized the total travel distances. Range anxiety, budget limit and recharged electricity of vehicle were considered as constraints [9]. He et al. developed a mathematical model and then solved by an iterative procedure. The charging station location problem is then formulated as a bi-level mathematical model and solved by genetic-algorithm based procedure [10]. Nakamura et al. presented a two-step methodology to find the minimal number and the location of charging stations. The first step generates delivery tour plans based on observed tour patterns. This input was used in the second step for the location optimization of charging stations. The proposed methodology was tested on a grid network under different parameter settings [11]. Zhou et al. proposed mathematical model to find optimal location of charging stations and how many chargers should be built to each charging stations to minimize the total cost. An expanded model which is genetic algorithm-based method (GA) was proposed to investigate the charging station location problem. The validity of GA was assessed on a case study based on a small city in Beijing, China [12]. Wu et al. proposed PROMETHEE and cloud model to present a solution to the location problem of EVCS. They applied the model to Beijing region to show the validity of the model [13]. Li et al. built a mixed integer linear program for the multi-period refueling location problem. The model was solved by a heuristic based on genetic algorithm. A case study of South Carolina shows the effectiveness and feasibility of the presented model [14]. Alegre et al. presented mathematic algorithm based on genetic algorithms and used Geographic Information System to plan charging stations. The aim of the model is to minimize the installation investment cost and the geographic distribution was improved in order to increase the quality of the service by improving reliability. The model was applied to Zaragoza, city of Spain [15]. Awasthi et al. developed a hybrid algorithm based on genetic algorithm and improved version of conventional particle swarm optimization, which considers the initial investment cost and distribution grid power quality as another parameter in the objective function, to find the optimal location and number of charging stations in the city of Allahabad, India [16]. Yang and Hu aim to minimize the investment cost of electric taxi charging stations by developing a data-driven optimization-based approach. By means of regression and logarithmic transformation, an integer linear program was formulated for the charger allocation problem and solved by Gurobi solver. The proposed method was applied to Changsha, China. The location of charging station was determined by using the proposed model and the optimal number of charging stations to allocate was obtained [17]. Wu and Sioshansi presented a model to optimize the location of a limited number of public fast charging stations for electric vehicles and a stochastic flow capturing location model (SFCLM) was used for the uncertainty in where EV charging demand appears and applied to Central Ohio based case study. A sample-average approximation method and an averaged two-replication procedure were used to solve the problem [18].

Although there are numerous studies in location selection of charging station, additional research is needed to meet the emerging EV market growth. This paper contributes to this effort by presenting an integrated model which takes many factors into consideration. In this study, only Level 2 charging stations will be considered in the location problem with regards to both cost and the needs of particular region. Because of the limited budget to buy EVSE and to supply its installation cost, it is logical to identify specific locations that requires EVSE to install mostly. The alternative points to locate the EVCS are determined and then ranked by using Analytic Hierarchy Process (AHP) with the consideration of given criteria in the first phase of the model (Fig 1). The input obtained from the first phase is used for the second phase of the model. Second phase includes mathematical model to determine the number of charging stations in different locations with a given budget.

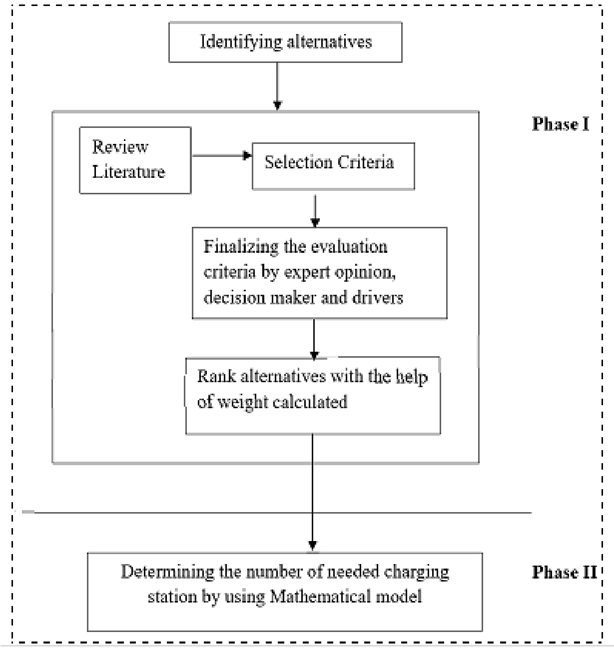

Fig 1. Flowchart of the proposed model

3 Proposed Methodology for Locating Electric Vehicle Charging Stations

For the location of Level 2 charging stations, shopping malls and cultural centers in Kadıkoy and Ataşehir are identified and these areas are sorted according to various criteria that are weighted by AHP methodology.

The identified criteria are first compared with respect to our goal by using AHP method. Then alternative points are compared with respect to three criteria. The performances of each candidate are obtained according to AHP calculations. These performances are used as an input for the mathematical model to obtain optimal number of charging station to locate.

3.1 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is a Multi Criteria decision making method, developed by Thomas L. Saaty. In AHP, the problem is built as a hierarchy dividing the decision from the top to the bottom. The goal is at the first level, criteria and sub-criteria are in the middle levels, and the alternatives are at the bottom level of the hierarchy which makes the problem more understandable and clear for the decision makers. Based on experts and decision makers evaluation of criteria, pairwise comparison is made which is the basis for the AHP and the best alternative is chosen according to the highest rank between alternatives [19].

If we wish to compare a set of n attributes pairwise according to their relative importance weights, where the attributes are donated by $a_1, a_2, \dots, a_n$ and the weights are donated by $w_1, w_2, \dots, w_n$, then the pairwise comparison can be represented by questionnaires with subjective perception as [20]:

$$A=\begin{pmatrix} a_{11}\cdots & a_{1j}\cdots & a_{1n} \\ \vdots & \vdots & \vdots \\ a_{i1}\cdots & a_{ij}\cdots & a_{in} \\ \vdots & \vdots & \vdots \\ a_{n1}\cdots & a_{nj}\cdots & a_{nm} \end{pmatrix} \quad (1)$$

where $a_{ij}=1/a_{ji}$ and $a_{ij}=a_{ik}/a_{jk}$. Note that in realistic situations w_i/w_j is usually unknown. Therefore, the problem for AHP is to find a_{ij} such that $a_{ij}\cong w_i/w_j$.

Weight matrix forms a square matrix; $W=w_i/w_j$ By multiplying W and w, it is obtained

$$(W-nI)w=0 \quad (2)$$

The solution of the above equation is the eigenvalue problem. We can derive the comparative weights by finding the eigenvector w with respective $\lambda_{\max}$ that satisfies $Aw=\lambda_{\max}w$, where $\lambda_{\max}$ is the largest eigenvalue of the matrix A, i.e., find the eigenvector w with respective $\lambda_{\max}$ for $(A-\lambda_{\max}I)w=0$.

Furthermore, in order to ensure the consistency of the subjective perception and the accuracy of the comparative weights, two indices, including the consistency index (CI) and the consistency ratio (CR), are suggested. The equation of the CI can be expressed as:

$$CI=\frac{\lambda_{\max}-n}{n-1} \quad (3)$$

where $\lambda_{\max}$ is the largest eigenvalue, and n donates the numbers of the attributes. Saaty (1980) suggested that the value of the CI should not exceed 0,1 for a confident result. On the other hand, the CR can be calculated as:

$$CR=\frac{CI}{RI} \quad (4)$$

where RI refers to a random consistency index, which is derived from a large sample of randomly generated reciprocal matrices using the scale 1/9, 1/8, 1/7, ... , 1, ... , 8, 9.

3.2 Mathematical Model

In recent years, the problem of where to locate the electric vehicle charging station has been formulated as mathematical model by many researchers.

The proposed mathematical formulation for our problem will be detailed in the next section.

4 Implementation of the Proposed Methodology

4.1 Study Area

EVCS location problem is both complicated and detailed problem that many factors must be taken into consideration to yield accurate results. For this reason, Kadikoy and Ataşehir, two districts of Istanbul, Turkey, has been selected to apply the provided model. Kadikoy is a large, populous, and cosmopolitan district of Istanbul on the northern shore of the Sea of Marmara. Ataşehir is located at the junction of the Motorway 2 (O-2) and Motorway 4 (O-4) in the Anatolian part of Istanbul (Fig. 2). High income level of the population of both Kadikoy and Atasehir is an important factor to choose these two districts for locating of charging stations. The other reason is Kadikoy and Atasehir are situated in central locations, therefore accessibility is relatively easier and people are eager to spend their leisure time in or around these districts.

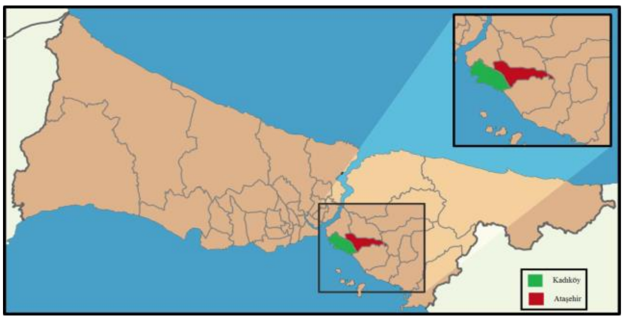

Fig. 2. Location of Kadikoy and Atasehir in Istanbul

4.2 AHP Based Weighting Method

In Istanbul, it is very common for people to spend their leisure time in shopping malls and cultural centers. These places provide consist of performance halls for concerts, theatre and exhibition hall, cafes and restaurants in addition to shopping stores. For this reason, we decided to identify 10 different shopping malls and cultural centers as alternatives in Kadikoy and Atasehir to locate Level II charging stations. The alternative points are shown in Fig. 3.

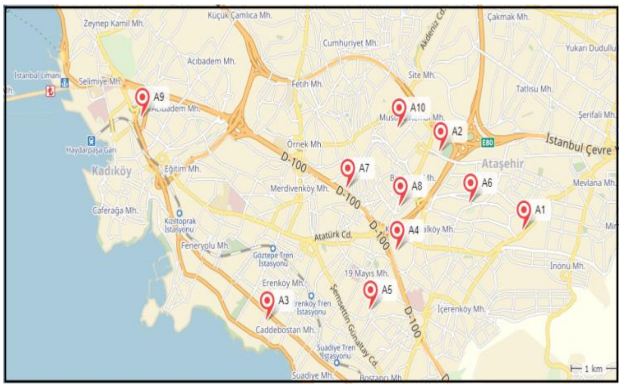

Fig 3. Alternative Points

In literature some studies are concentrated on multi criteria decision making (MCDM) methodologies to find out optimal locations of EVCS. Many criteria are considered to make a good decision in this process. Efthymiou et al. used multi-criteria analysis (MCA) technique to find an optimal location of charging stations and applied it to the municipality of Kalamaria in Thessaloniki, Greece. A number of criteria, the population characteristics, points of interest and the characteristics of the electric utility around the candidate position, were weighted in order to bear the weight of decision makers [21]. Guo and Zhao discussed MCDM to examine some subjective but significant criteria for EVCS location selection. Fuzzy TOPSIS method was used to find optimal EVCS locations. Environment, economy, society and technology criteria were proposed and each of these criteria has their own sub-criteria. Economy criterion has various sub-criteria which are: investment pay-back period, total construction cost, annual economic benefit, internal rate of return, land acquisition costs, annual operation and maintenance costs, causeway construction costs, removal cost. Society criterion has some sub-criteria which are: impact on living level of residents, service capacity, traffic convenience, coordinate level of EVCS with urban development planning. Environment criterion has some sub-criteria which are: deterioration on soil and vegetation, atmospheric particulates emission reduction, greenhouse gas emission reduction. Technology criterion has mainly three sub-criteria which are: substation capacity permits, power quality influence and power grid security implications [22]. Liu et al. used the Delphi method (Delphi), grey statistics method of decision-making and AHP methodology to assess the location of charging stations. They integrated Grey Analytic Hierarchy Process (GAHP) and Delphi method to build a new evaluation method. They introduced four criteria which are traffic convenience, economy, technical feasibility and influence rationality to evaluate EVCS candidates [23]. Xu et al. proposed a geometric reasoning method to find the optimal locations for Level 2 and DC charging. Geometric reasoning method consists of two modules: Planning Module to define the variables, Facility Module to determine user utility of the charging stations. They built optimization model taking the maximization of utility score as the selection criterion. Accessibility, time availability, power grid capacity and neighborhood safety variables are considered to select the ideal locations of EVCs [24]. Jia et al. formulated the mathematical expression of each factor they defined which are charging demand, user behavior patterns, road network structure, cost of charging station construction and operation, charging costs of users and other factors and built model to optimize the number and location of EVCS to minimize the investment cost. The data of Stockholm, Sweden was used to validate the model [25]. Tang et al. used Voronoi Diagram to divide the zone, in which a charging station is built and then proposed fuzzy analysis and AHP methodology to optimize the optimal sitting of charging station. It was made a qualitative and quantitative analysis by integrating fuzzy and AHP. They presented some main criteria and their sub-criteria to evaluate the candidate sites. Transportation criterion has road conditions and main roads sub-criteria, economy criterion has cost of operation and maintenance, total cost of construction investment, cost of wear and tears. Society criterion is divided into four sub-criteria which are resource distribution, technical conditions, construction conditions and local government's opinion. Effect criterion has people life, power grid safety and environmental impact sub-criteria [26]. Yağcıtekin et al. considered six criteria which are: number of parking areas that have charging unit(s), walking distance, distance between power substations and parking areas, density, expandability and accessibility [27].

As described above, the criteria are mainly related to economic, social, environmental, and technical issue. We do not consider economy criterion because it will be considered in mathematical formulation. Because we aim to rank shopping malls and cultural centers, the evaluation criterion of visitors for these places are taken into consideration. For this reason, following criteria are finalized by the expert opinion and drivers feedback about shopping malls and cultural centers. We asked five electric vehicle drivers to evaluate the criteria and we built consensus with two experts.

C1: Accessibility: Ease access to the shopping malls and cultural centers. Visitors do not want to waste time trying to reach to the shopping mall because of the distance. The range of operating hours of the shopping malls should allow visitors to access any time.

C2: Car parking situation: Car parking capacity must be enough for people who come to the mall by car. Lack of parking area can change visitors' idea to choose a different shopping mall. Entrance and exit to the parking place should be convenient for drivers. It is important not to hinder traffic flow in the parking area.

C3: Traffic convenience: Traffic flow near the shopping mall should be good. Istanbul is a crowded city and traffic jam occurs continuously. People particularly want to feel comfortable when going somewhere in their leisure time. Hence traffic convenience is an important criterion when making decision.

The evaluation of the criteria is finalized by the expert opinion and drivers' feedback about shopping malls and cultural center. The hierarchy is configured and the criteria are calculated by using Super Decision 2.0.8 Programs which is decision support software that implements the AHP and Analytic Network Process (ANP). Overall composite weight of the alternatives is got after the calculations in Super Decision 2.0.8 Programs.

Table 2. Comparison of Criteria with respect to Goal

Priority	C1	C2	C3	Priority	Inconsistency Ratio
C1	1.0	0.5	3	0.319	CR = 0.01759
C2	2	1.0	4	0.558	
C3	0.33	0.25	1.0	0.121	

The three criteria are compared and the results are shown in Table 2. It is obtained that car parking situation of the shopping malls is the most important criterion for EV drivers according to priority result. Accessibility is the second most important and traffic convenience the least important criteria for EV drivers. CR is under 0.1 which shows that the results are reliable.

Table 3. Comparison of Alternatives with respect to Accessibility

C1	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	Priority
A1	1.0	2	4	0.16	4	2	0.16	1.0	0.3	2	0.075
A2	0.5	1.0	4	0.16	4	2	0.16	0.5	0.25	1.0	0.056
A3	0.25	0.25	1.0	0.16	1.0	0.33	0.16	0.33	0.2	0.33	0.023
A4	6.0	6.0	6	1.0	6	3	1.0	3	2	3	0.226
A5	0.25	0.25	1.0	0.16	1.0	0.33	0.2	0.33	0.25	0.33	0.025
A6	0.5	0.5	3.0	0.33	3.0	1.0	0.2	1.0	0.25	0.5	0.049
A7	6.0	6.0	6.0	1.0	5.0	5.0	1.0	5	2	5	0.256
A8	1.0	2.0	3.0	0.33	3.0	1.0	0.2	1.0	0.25	1.0	0.063
A9	3.0	4.0	5.0	0.5	4.0	4.0	0.5	4.0	1.0	4	0.165
A10	0.5	1.0	3.0	0.33	3.0	2.0	0.2	1.0	0.25	1.0	0.059

The alternative locations are compared with respect to accessibility criterion and the results are shown in Table 3. Alternative point 7 (A7) is the most preferable shopping mall according to priority value which is 0.256. Alternative point 3 (A3) is the least preferable place with the value of 0.023. The value of inconsistency ratio is 0.04854 which provides consistent results.

Table 4. Comparison of Alternatives with respect to Car Parking Situation

C2	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	Priority
A1	1.0	2	5	0.5	4	2	0.33	0.5	1.0	0.2	0.085
A2	0.5	1.0	4	0.5	3	1.0	0.5	0.5	2	0.2	0.071
A3	0.2	0.25	1.0	0.33	1.0	0.33	0.33	0.25	0.33	0.2	0.028
A4	2.0	2.0	3.0	1.0	4	2	2	0.5	2	0.33	0.121
A5	0.25	0.33	1.0	0.25	1.0	0.5	0.33	0.33	0.5	0.25	0.033
A6	0.5	1.0	3.0	0.5	2.0	1.0	0.5	0.33	0.5	0.25	0.055
A7	3.0	2.0	3.0	0.5	3.0	2.0	1.0	1.0	2	0.25	0.114
A8	2.0	2.0	4.0	2.0	3.0	3.0	1.0	1.0	3	0.33	0.139
A9	1.0	0.5	3.0	0.5	2.0	2.0	0.5	0.33	1.0	0.33	0.066
A10	5.0	5.0	5.0	3.0	4.0	4.0	4.0	3.0	3	1.0	0.282

The alternative locations are compared with respect to car parking situation and the results are shown in Table 4. Alternative point 10 (A10) is the most preferable shopping mall because it has the highest priority value. Alternative point 3 (A3) is the least preferable place because it has the lowest priority value. The value of inconsistency ratio is 0.04830 which gives reliable results.

Table 5. Comparison of Alternatives with respect to Traffic Convenience

C3	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	Priority
A1	1.0	5	5	4	5	4	4	1.0	3	2	0.230
A2	0.2	1.0	5	3	5	0.33	3	0.5	0.25	0.5	0.089
A3	0.2	0.2	1.0	0.2	1.0	0.5	0.2	0.25	0.5	0.16	0.026
A4	0.25	0.33	5.0	1.0	3	0.33	1.0	0.33	3	0.5	0.073
A5	0.2	0.2	1.0	0.33	1.0	0.33	0.25	0.25	0.5	0.33	0.028
A6	0.25	3.0	2.0	3.0	3.0	1.0	3	0.5	2	0.5	0.113
A7	0.25	0.33	5.0	1.0	4.0	0.33	1.0	0.33	1.0	0.33	0.060
A8	1.0	2.0	4.0	3.0	4.0	2.0	3.0	1.0	3	1.0	0.157
A9	0.33	4.0	2.0	0.33	2.0	0.5	1.0	0.33	1.0	0.33	0.076
A10	0.5	2.0	6.0	2.0	3.0	2.0	3.0	1.0	3.0	1.0	0.143

The comparison of alternatives with respect to traffic convenience is illustrated in Table 5. Alternative point 1 (A1) is the most preferable shopping mall according to priority value which is 0.230. Alternative point 3 (A3) is the least preferable place with the value of 0.026. The value of inconsistency ratio is 0.09990 which means it yields reliable results.

The overall weight is obtained by the product of the weight and priority vector (Table 6).

Table 6. Overall composite weight of the alternatives

	C1	C2	C3	Composite Weight
Weight	0.319	0.558	0.121	
A1	0.075	0.085	0.230	0.0998
A2	0.0563	0.071	0.089	0.0690
A3	0.023	0.028	0.026	0.0270
A4	0.226	0.121	0.073	0.1491
A5	0.025	0.033	0.028	0.0301
A6	0.049	0.055	0.113	0.0605
A7	0.256	0.114	0.060	0.1530
A8	0.063	0.139	0.157	0.1175
A9	0.165	0.066	0.076	0.0995
A10	0.059	0.282	0.143	0.1942

4.3. Proposed Mathematical Programming Approach

In our model, we aim to find the optimal number of charging stations by maximizing drivers' utility. We consider various factors and constraints:

Indexes:
i: Index of charging stations, {i = 1,2,..,10}

Parameters:
C_i: cost of charging station to build in location i (cost includes EVSE unit cost, installation cost, operation and maintenance costs),
W_i: weight factor for location i,
B: available budget to build charging station,
K_i: the capacity of the station at site i,

Decision Variales:
X_i: number of charging station to be located

Mathematical Model:

Maximize $$\sum_{i=1}^{10} W_i X_i \quad (5)$$

Objective function (5) aims to maximize the user utility by considering weights (w_j) of each alternative point. The weight of each alternative is obtained by the evaluation of users.

Subject to $$\sum_{i=1}^{10} C_i X_i \leq B \quad (6)$$

The budget constraint set (6) provides the number of charging station to install. We can buy a certain number of charging station under a budget limit. For this reason, a budget is allocated to determine how many station to install. We consider costs as EVSE unit cost, installation cost, operation and maintenance costs.

$$\sum_{i=1}^{10} X_i \leq K_i, \forall i \quad (7)$$

The constraint set (7) ensures that each alternative location has a certain capacity to install EVCS.

$$X_i \geq 0 \ , \forall i \quad (8)$$

Constraint (8) ensures that the number of charging station to locate is equal or greater than 0.

4.3.1. Data Set:

We obtained weights for each shopping mall by AHP calculations (Table 6. Overall composite weight of the alternatives). We considered electric vehicle supply equipment EVSE unit cost, installation cost, operation and maintenance costs for each shopping mall. We took average EVSE unit cost for Level II is as $3,209. Operation and maintenance cost and installation cost which includes trenching, supplying electrical service to charging station, charter price to locate EVCS, differ for each shopping mall. We asked each utility for these data and we considered related Projects feasibility reports. According to this study we get the cost results as shown in Table 7.

Table 7. Data Set

I	Weight	Cost ($)	Capacity
A1	0.0998	7,450	4
A2	0.0690	6,985	3
A3	0.0270	6,970	2
A4	0.1491	8,450	5
A5	0.0301	7,180	2
A6	0.0605	7,150	4
A7	0.1530	8,120	4
A8	0.1175	8,050	5
A9	0.0995	8,550	5
A10	0.1942	7,450	4

The model was solved in LINGO 17.0 Solver optimization tool. According to LINGO results we obtained optimal number of charging stations as illustrated in Table 8.

Table 8. Number of Charging Station to be located to each shopping mall

I	Number of charging stations to be located (X_i)
A1	4
A2	1
A3	0
A4	5
A5	0
A6	0
A7	4
A8	5
A9	4
A10	4

5 Conclusion

In this paper, we address the problem of where to locate charging stations in districts of Istanbul. The problem of where to locate electric vehicle charging station can be grouped as a decision making problems because of including many criteria and alternatives that have to be considered simultaneously. Therefore, we identified 10 alternative locations in Kadikoy and Ataşehir, two districts of Istanbul. We formed three main criteria from the literature review to compare these alternative locations with each other. AHP methodology is used to obtain composite weight of each alternative locations and to rank these alternative locations. Then we used these weights as an input for mathematical model to obtain optimal number of charging station to locate for each alternative locations. Because the installation of EVCS is costly and we have a limited budget to buy EVCS, considering the weights that we obtained from AHP methodology is significant. That is why AHP methodology was integrated with mathematical model.

In the literature, there are studies based on MCDM methods and optimization models upon locating EVCS, however; on the basis of Turkey, neither MCDM based method nor mathematical model have been used together in a study which is about EVCS location. However, because EVs are new technology in Turkey and the number of EV drivers are few, the range of criteria we defined is few and so evaluation of them can be difficult. This problem will be solved as the number of vehicles increases over years.

For further studies, proposed methodology may be extended and applied to all districts of Istanbul by adding more constraints and crtiteria. Other integrated methodologies may be developed and applied for EVCS location problem.

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