LOCATING ELECTRIC VEHICLE CHARGING STATIONS IN ISTANBUL WITH AHP-TOPSIS BASED MATHEMATICAL MODELLING

(AHP-TOPSIS TEMELLİ MATEMATİKSEL MODELLEME İLE İSTANBUL’ da ELEKTRİKLİ ARAÇ ŞARJ İSTASYONLARININ KONUMLANDIRILMASI)

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LIST OF SYMBOLS

EV	**:** Electric Vehicle
EVCS	**:** Electric Vehicle Charging Station
MCDM	**:** Multi Criteria Decision Making
EVSE	**:** Electric Vehicle Supply Equipment
AHP	**:** Analytical Hierarchy Process
TOPSIS	**:** Technique for Order Preference by Similarity to Ideal Solution

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ABSTRACT

Growing concerns about the increasing consumption of fossil energy and the improved recognition of environmental protection requires sustainable road transportation technology. Electric vehicles (EVs) can contribute to improve environmental sustainability and to lower the pollution level. As many countries switch to EVs, the amount of them will increase notably. However, the transition to EVs is currently facing various shortcomings among which are: the high cost of EV batteries and their limited driving range, the lack of technology breakthrough and underdeveloped charging station infrastructure. To overcome these shortcomings, it is significant to install sufficient charging station to the critical sites. If charging infrastructure improves, there will be a growth in public motivation for this technology through decreasing EV owners' concern about the mileage range. The primary objective of this study is to use an integrated methodology to rank the optimal sites of electric vehicle charging stations and to find the optimal number of EVs charging station in districts of Istanbul, Turkey. Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methodologies are presented in the first phase of the thesis and in the second phase mathematical model is used to find the optimal number of electric vehicle charging stations. In the first phase, the alternative points are identified and the decision criteria for the charging station site selection are presented. The performance of each alternative point with respect to criteria is obtained using AHP method. Then, TOPSIS method is applied to rank the alternative points with the help of weights calculated by AHP. In the second phase, a mathematical model is formulated to maximize the user utility and to find the optimal number of charging station for each alternative point. The results are discussed and the conclusion is provided.

ÖZET

Son yıllarda artan fosil yakıt tüketimi ve ayrıca çevre bilincindeki artış, sürdürülebilir karayolu taşımacılığı teknolojilerine olan ihtiyacı zorunlu kılmaktadır. Elektrikli araçlar, çevresel sürdürülebilirliğin geliştirilmesine ve hava kirliliği seviyesinin düşürülmesine katkıda bulunur. Birçok ülke elektrikli araçlara geçiş yaptıkça, yollarda bulunan elektrikli araç miktarı önemli ölçüde artacaktır. Bununla birlikte, elektrikli araçlara geçiş, elektrikli araç bataryalarının yüksek maliyeti ve aracın gidebileceği menzilin sınırlı olması, yeni teknolojilerin eksikliği ve şarj istasyonu altyapısının yetersizliği gibi çeşitli durumlarla karşı karşıyadır. Bu problemlerin üstesinden gelmek için kritik bölgelere yeterli sayıda şarj istasyonu kurmak önemlidir. Şarj istasyonu altyapısı gelişirse, elektrikli araç sahiplerinin menzil hakkındaki endişeleri azalacak ve böylece bu teknolojinin sürücüler arasında yaygın biçimde kullanılmasında bir artış olacaktır. Bu çalışmanın temel amacı, İstanbul'un çeşitli ilçelerinde elektrikli araç şarj istasyonlarını en uygun yerlere ve en uygun sayıda yerleştrilmek için entegre bir metodoloji geliştirmektir. Tezin ilk aşamasında AHP ve TOPSIS metodolojileri kullanılmış ve ikinci aşamasında optimal şarj istasyon sayısını bulmak için matematiksel bir model geliştirilmiştir. İlk aşamada alternatif konumlar ve bu konumların önceliklerinin belirlenmesi için karar kriterleri tanımlanmıştır. Her bir alternatif konumun kriterlere göre performansı AHP metodu kullanılarak elde edilmiştir. Daha sonra, alternatif konumları sıralamak için TOPSIS metodu kullanılmıştır. İkinci aşamada, kullanıcı faydasını maksimize etmek ve her bir alternatif konuma yerleştirilecek optimum sayıdaki şarj istasyon sayısını bulmak için matematiksel model formüle edilmiştir. Çalışma sonucunda elde edilen sonuçlar tartışılmıştır.

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 (Afroditi et al., 2014). Furthermore urban freight and commercial vehicles cause a significant share of unhealthy air pollutants such as sulphur oxide, particulate matter, and nitrogen oxides in urban areas (Capasso et al., 2014). 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 (Feng and Figliozzi, 2012).

By mid-September 2015, over one million highway legal plug-in electric passenger cars and light utility vehicles have been sold worldwide, representing less than 0.1% of the world's stock of motor vehicles, estimated at 1.2 billion vehicles by mid 2014. As of 2016, the United States has more than 570,000 EVs (Cobb, 2017 ; Cobb, 2017). China has the largest stock of highway legal light-duty plug-ins with cumulative sales of more than 645,000 EVs (Cobb, 2016). Japan has 147,500 plug-ins. More than 637,000 light-duty passenger EVs had been registered in Europe, representing 31.4% of global sales. Sales in the European light-duty EV segment were led by Norway (135,000 units), followed by the Netherlands (113,000) and France (108,000) (Cobb, 2017). Developed countries consider the importance of the EVs and thus the number of EVs on road increase year by year. Unlike these countries, the advancement of EVs in Turkey is moderate. The first electric vehicles (EVs) were sold in Turkey in 2012. The quantity of EVs on the road is insignificant. In the first eight months of 2016, 35 electric cars were sold.

Driver habits and the short distances that can be covered by an EV are two main reasons. Turkish people mostly prefer to drive their own car even for long distances. However, available batteries do not support such long trips. Another significant reason is inadequate charging infrastructure. (Yazgan Van Herk and Nuijens, 2015). Because EV number on the road is few, the need for charging station is correspondingly low. The insufficient deployment of charging stations across Turkey is one of the main problem.

Since the use of EVs increases gradually in the world and EVs are an emerging market in Turkey, it has some limitations such as long time required by the charging process, limited life of batteries and their cost, lack of recharging infrastructures with public access. The existing infrastructure in Turkey is inadequate and the needed infrastructure to install is expensive. Investment on research and development (R&D) and the number of R&D personnel are low. Specific plans are aimed to put into action in order to reduce costs, increase charging capacity, increase electric drive and system efficiencies and to build the infrastructure so as to spread the use of electric vehicles. The actions are to enable charging at home, increase the accessibility of charging stations (in big cities 1 station in every 30km), improve the availability of fast charging stations, establishing a contactless charging infrastructure (Yazgan Van Herk and Nuijens, 2015).

There are mainly five companies in electric vehicle charging station business that are currently active in the Turkish market: Eşarj, Fullcharger, Yeşil Güç, BD OTO and Gersan. There are companies that have the technology, strategies and action plans, but prefer to wait until the market becomes more active (Yazgan, 2013).

As the number of electric vehicles on the road increases, the increase is expected in the demand for charging stations. For this reason, having sufficient charging station infrastructure has made it necessary for this technology to be held in the market. 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. When it becomes easy to access to the charging stations, electric vehicles adoption rates, petroleum demand and electricity consumption across the times of a day will be affected (Gavranović et al., 2014)

1.1 Research Objectives and Methodology

Based on the previous discussion, the purpose of this thesis is to decide the number of charging stations in different locations within a given budget and locate EVs on the appropriate sites to meet drivers' convenience in Istanbul, Turkey by using an integrated method. In the first phase of the proposed model, the alternative points to locate charging stations are identified. In the second phase, it is aimed to maximize user utility and to find the optimal number of EVCS by using mathematical model.

1.2 Organization of Thesis

The remainder of this thesis is structured as follows. Chapter 2 reviews the literatures related to the location of electric vehicle charging stations and then defines the main contributions of this paper. Chapter 2 also gives a short summary of thehistory of EVs.

In Chapter 3 the proposed methodology is presented. Alternative locations are identified for the sitting of charging stations. Two different modelsareintegrated to rank the alternative locations for charging stations to provide an input for mathematical model. Multi Criteria Decision Making (MCDM) is used for selecting locations of charging stations.

The decision criteria of the charging station site selection are presented and evaluated. The weights of each criteria are calculated by using AHP. Alternatives locations are ranked by TOPSIS with the help of weight calculated by AHP. The optimal number of charging stations is obtained by using mathematical model with the given budget.

Chapter IV presents implementation and last chapter (Chapter 5) provides the conclusion.

2. LITERATURE REVIEW

2.1 History of Electric Vehicles

Electric vehicles (EVs) were introduced more than 100 years ago and today they are seeing a rise in popularity. It is hard to pinpoint the invention of the EV to one inventor or country. Instead it was a series of breakthroughs -from the battery to the electric motor- in the 1800s that led to the first EV on the road (Matulka, 2014).

First crude electric carriage was invented in 1832 by Robert Anderson, a British inventor. Then, American Thomas Davenport made the first practical EV – a small locomotive in 1835. French physicist Gasten Planté invented the rechargable lead-acid storage battery in 1859. A chemist from the United States William Morrison built the first successful electric automobile in 1891 (Matulka, 2014).

In the beginning of 1900, the electric automobile was in its heyday. In the USA, the percentage of electric car use was 28. Because of the drawbacks of electric cars, 1920s were a stagnation period for them. The reasons of electric cars' downfall were the desire for longer distance vehicles, their lack of horsepower and the ready availability of gasoline (Matulka, 2014).

The soaring price of oil and the environmental issues resulted in renewed interest in EVs as from the 1970. During this time, automakers began modifying some of their popular vehicle models into EVs. One of the most well-known electric cars was General Motors (GM)' s EVI. This vehicle was designed and developed from the ground up. Due to the high production costs, GM had to cease the project in 2001. The first mass-produced hybrid EV Toyota Prius was released in Japan in 1997. It was the turning point. It took the attention from the celebrities and as a result made an instant success.

As the oil prices rose and air pollution issue started to take attention, Toyota Prius became best selling hybrid car around the world. Then Tesla Motors produced a luxury electric sports car which helped to reshape EVs. The success of Tesla Motors's car encouraged other automakers to invest on EVs. In the late 2010, the Cevy Volt and Nissan LEAF were released in the US market. Over the next few years, other automakers offered electric vehicles, however consumers were faced with the problem of where to charge their vehicles. To solve this problem, the Energy Department of the USA funded to help build a nation-wide charging stations. Automakers and other private businesess installed their own charging stations (Matulka, 2014).

2.2 Background of Electric Vehicle Supply Equipment

Level 1, Level 2, and DC fast charging are three primary types of electric vehicle supply equipment (EVSE). EVSE units are available in different amperage ratings. The vehicle charging time depends on the state of charge of the battery (Smith and Castellano, 2015). The differences in supply power and charging time for Level 1, Level 2, and DC fast charging are illustrated in Table 2.1.1.

Table 2.2.1: Electric Vehicle Supply Equipment Types

Charging Level	Supply Power	Charging Time
Level 1	220 – 240V/16A	6 – 8 hours
Level 2	380V/16A	3 – 4 hours
DC Fast Charging	380V/32A	30 minutes – 1 hour

Level 1 charging stations can be suitable for home use. Level 1 is most useful when a vehicle will be parked for several hours.

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.

2.3 Related Work

In the literature, there are a number of studies that use different methods to determine the location of electric vehicle charging stations. It is possible to classify these studies according to the methods used.

The EV use is currently facing various shortcomings among which are: limited driving range, high cost (Touati-Moungla and Jost, 2012) and underdeveloped supporting infrastructure (Nie and Ghamami, 2013). Several methods were developed to overcome these shortcomings. Ying-Wei Wang (2007) used integer program to determine the optimal locations of electric vehicles' recharging stations and applied it to Penghu, Taiwan. Penghu is a touristic city and visiters use electric scooters to see the historical and recreational sites of the city. Because electric scooters' range is limited, it is important to widen the recharging stations. The aim of the study is to suggest favorable recharging stations to tourists. The proposed location model is based on fleet size, locating capacity, cost, and mean length of stay at destinations and it was concluded that the model is appropraite.

Wang and Lin (2009) used the concept of set cover to offer a refueling-station-location model using mixed integer programming and applied to Taiwan. It was obtained from sensitivity analysis that larger vehicle range will result in a lower number of refueling stations.

In their study Ying-Wei Wang and Chuan-Ren Wang (2009) proposed a hybrid model that follows the concept of set cover and vehicle refueling logics. They used mixed integer programming method to locate refueling stations economically and with maximum coverage. The model was appropraite to the case of fast-refueling-station planning on

Taiwan's road network, and it was concluded that vehicle range and the predetermined coverage distance have a crucial role in the result.

Feng et al. (2012) proposed weighted Voronoi diagram and mathematical model for electric vehicle charging station planning. Road network structure, traffic density and users' loss on the way to the charging station were considered in the mathemetical model. The users' minimum loss on the way to the charging station was decided as the objective function for locating the charging station. Weighted Voronoi diagram was applied to divide the road network of planning area. It was understood from the practical example that the models were convenient.

Ge et al. (2012) constructed a mathematical model to minimize the investment cost of electric vehicle charging stations. Maximum and minimum number of charging stations were decided based on maximum and minimum capacity of charging stations. Taking into consideration of distribution network, an optimal modeling program which is Voronoi Diagram was used to divide station service area. The allocations of charging stations were optimized by using the queuing theory. The proposed models were applied to a case study. The results showed the effectiveness of the models.

In their study Feng et al. (2012) developed a planning model of charging stations on the trunk road. They took into consideration the power distribution and the mileage of electric vehicles. The plan and capacity allocation of charging stations were analysed. It was understood that the performance of the model was feasible.

He et al. (2012) proposed Multiple-Population Hybrid Genetic Algorithm (MPHGA) and applied to a small city. The model had effective results on the application of the city.

Zifa et al. (2012) used mathematical method to reduce the cost of charging stations. They considered traffic flow situation as constraint conditions and set up a new electric vehicle charging station locating and sizing model. They benefited from the particle swarm optimization (PSO) algorithm to solve the problem and applied it to a district in Beijing.

It was understood that PSO is fast, however it has some drawbacks. It was obtained from the application results that mathematical model and PSO are efficient and feasible.

He et al. (2013) defined the transportation and power networks and established an equilibrium modeling framework. They applied the modeling framework to decide an optimal allocation of a given number of public charging stations among metropolitan areas. They developed mathematical program to find an optimal allocation of public charging stations and solved by an active-set algorithm. The proposed model in this study depends on a critical assumption and these assumptions needs to be validated.

Dong et al. (2014) proposed an activity-based assessment method to evaluate battery electric vehicle (BEV) feasibility. Genetic algorithm was used to find optimal locations for placing public charging stations and was applied to Seattle metropolitan area. It was clarified that insalling public chargers at frequent places could increase electric miles. The warning of this study is the belief that current activity patterns with gasoline powered vehicles will not change when transforming to electric vehicles.

Liu et al. (2013) analyzed optimal locations of EV charging stations by a two-step screening method. Then mathematical model was developed to minimize the cost of EVs including infrastructure cost, investment cost, maintenance cost, operation costs and network loss cost in the planning period. The constucted model was solved by Modified primal-dual interior point algorithm (MPDIPA). The results show that the proposed methods and models are applicable for the EV charging station prolem.

Xi et al. (2013) established a simulation–optimization model to decide the optimal location of electric vehicles and applied it to the central-Ohio region. They aimed to maximize the use of electric vehicles by privately owned electric vehicles. They proposed the combination of level-one and level-two chargers. This proposed combination yielded to maximize the charging energy available and ensitivity analyses results verified their modeling approach.

Wang et al. (2013) developed a quantitative model and a location model along intercity road by presenting a number of parameters such as regional coefficients of variation and attraction coefficient of charging stations. The model, which was based on the oil sales transaction, aimed to design the layout of urban charging stations. It was obtained that the model was suitable to the optimization calculation of the charging stations of the electric vehicles.

González et al. (2014) used an activity-based (ActBM) microsimulation model to analyse the drivers' daily activities and applied it to Flanders region, Belgium.

Cavadas et al. (2015) presented a mathemetical model for siting EV charging staions and applied to Coimbra in Portugal. Acticity- based approach presents advices only on areas with higher demand expectancy. While mathematical model involves demand transference. In this study mathematical model produces efficient results but when it is applied to a large scale city, the results may not be the same bacause of the increasing of computation complexity.

You and Hsieh (2014) proposed a mixed-integer programming model to point the problems of electric vehicles such as range anxiety, high infrastructure cost of charging stations. It was used hybrid heuristic approach to solve this problem. The results demonstrated that hybrid heuristic approach was more efficient than conventional genetic algorithm.

Chung and Kwon (2015) proposed multi-period optimization (M-opt) method and compared it with forward-myopic (F-myopic) method and backward-myopic (B-myopic) method to bring a solution to the problem of the location of charging stations. It was obtained that the differences among the results of the three methods are small in Korean Expressway case study.

Baouche and Billot (2014) proposed a methodology for the optimal location of charging stations and applied to the city of Lyon. The methodology depended on an adaption of the classic fixed charge location model with a p-dispersion constraint. The results showed that this methodology could be useful for the future implementation of charging stations at an urban scale.

Lam et al. (2014) aimed to minimize construction cost of EV charging stations and locate EVs on the appropriate places to fulfill drivers' convenience. They formulated the problem as an optimization model based on the charging station coverage and the convenience of drivers. They proposed four different methods to tackle the problem and evaluated them to understand which one is the most suitable for the problem. The proposed methods are Iterative Mixed-Integer Linear Program, Greedy Approach, Effective Mixed-Integer Linear Program and Chemical Reaction Optimization. According to the simulation result these methods have their own pros and cons. The most suitable one could be chosen according to the need.

Riemann et al. (2015) examined the optimal locations of charging facilities, wireless power transfer facilities, and used mathematical model to point the problem. The objective of the model is to site wireless charging facilities for EVs to yield maximum traffic flow on a network. The model was verified by numerical examples.

Shahraki et al. (2015) presented an optimization model considering 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. It was understood that increasing the total number of charging stations expand the locations of the optimal stations outward from the inner city.

Sadeghi-Barzani et al. (2014) proposed a Mixed-Integer Non-Linear (MINLP) optimization approach for the optimal location of charging stations. They aimed to minimize the total cost of charging station development, electric grid loss and electric vehicle loss because of the charging travel. Fast charging integration into grid technology was important to meet the customer demand quickly and for the sustainability. Genetic algorithm technique was used to solve the optimization problem. The poposed method had efficient results.

Zhou et al. (2016) proposed mathematical problem to find the optimal location of charging stations and how many chargers should be build in each charging stations to minimize the total cost. An expanded model which is genetic algorithm-based method (GA) was also proposed to investigate the charging station location prolem. The validity of GA was assessed on a case study based on a small city in Beijing, China.

R.J. Flores et al. (2016) aimed to decide the cost to buy electricity from a utility to supply electricity to a public Level 3 electric vehicle supply equipment with careful assessment of available electric utility rate structures, as well as the cost to refuel individual PEVs. They propose a supportive analysis of Level 3 EVSE.

Mehar et al. (2013) proposed a mathematical model to determine the appropriate strict constraints and cost of charging stations' location. And then they proposed an optimized algorithm to locate electric vehicles charging stations (OLoCs) and determine the necessary number of electric vehicle. The results showed that OLoCs is an efficient method in terms of time and optimality.

Wu et al. (2016) 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. The model can identfy the uncertainty of information. The decision system is easy to use, which contributes to improving the flexibility.

Xu et al. (2013) used geometric reasoning method to decide the number and site of Level II and DC charging stations. The proposed methods were applied to Akren area of Ohio to show the validity of them. By means of integrated modeling and mathematical optimization, it is demonstrated that the proposed model is capable of selecting proper locations for electric charging stations based on constraints in a given socioeconomic environment.

Chen and Hua (2014) took the traditonal gas stations as candidate sites and proposed a new model based on set cover model to select the optimal ones. The objective is to choose suitable sites that each driver will exhaust the least emission on the way. They proposed an optimization model that minimizes the total cost of the deployment of the charging stations, including transportation cost and the environmental cost. The proposed model offers useful solution for the government that plans building charging stations.

Jinet al. (2012) used mathematical multi-level layout planning model to minimize initial construction investment and users' charging cost and to build reasonable amount of electric vehicle charging stations with proper locations. A Genetic Algorithm was proposed to solve the layout model. The result of empirical case study has proved the effectiveness of our algorithm.

Wang and Lin (2008) proposed a refueling-staion-location model under the concept of set cover modeling and used mixed integer programming method based on vehicle routing logics. Soorigin-destination (O-D) matrix is needed to solve the problem. Taiwan case study shows the applicability of the model. The limitation of the proposed model is that it was based on the assumptions of a sufficient budget for station deployment. However, the traffic volume is different on each path and financial and other resources must be taken into consideration. That is why maximum covering problem was developed.

2.4 Concluding Remark

Although there are numerous studies in facility location, additional research on EVCS location problem 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. 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. As illustrated in Figure 2.4.1, the alternative points to locate the EVCS are determined and then sorted by using integration of Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods with the consideration of given criteria in the first phase of the model. 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.

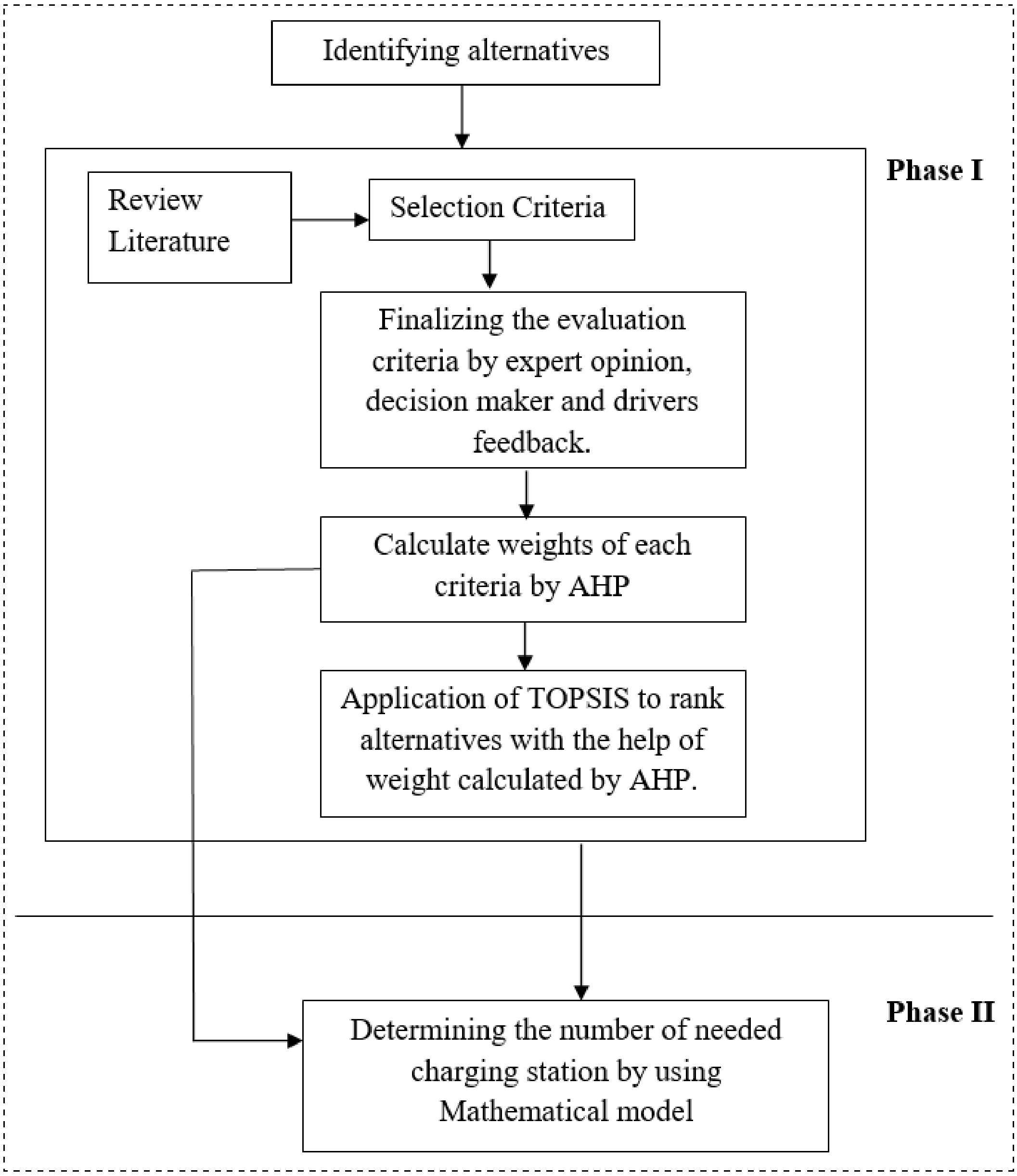


Figure 2.4.1: Flowchart of the proposed model

3.MATERIALS AND METHODS

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

3.1 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is one of Multi Criteria decision making method that was originally developed by Thomas L. Saaty. In AHP, the problem is built as a hierarchy dividing the decision from the top to the bottom. As illustrated in Figure 3.1.1, 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 (Rimal Abu Taha, 2011). AHP structures the decision problem into levels that correspond to a decision maker's understanding of the situation: goals, criteria, sub-criteria, and alternatives, so that the decision maker can focus on smaller sets of decisions. The purpose of AHP method is to obtain quantitative scores and weights from qualitative statements on the relative performance of alternatives and the relative importance of criteria obtained from comparison of all pairs of alternatives and criteria. It should be noted, that the AHP method can be useful to evaluate relative criteria weights and to evaluate the performance of alternatives through pairwise comparisons. The final table of pairwise comparisons are translated to weights and scores using the Eigenvalues of these tables (Zardari et al., 2015).

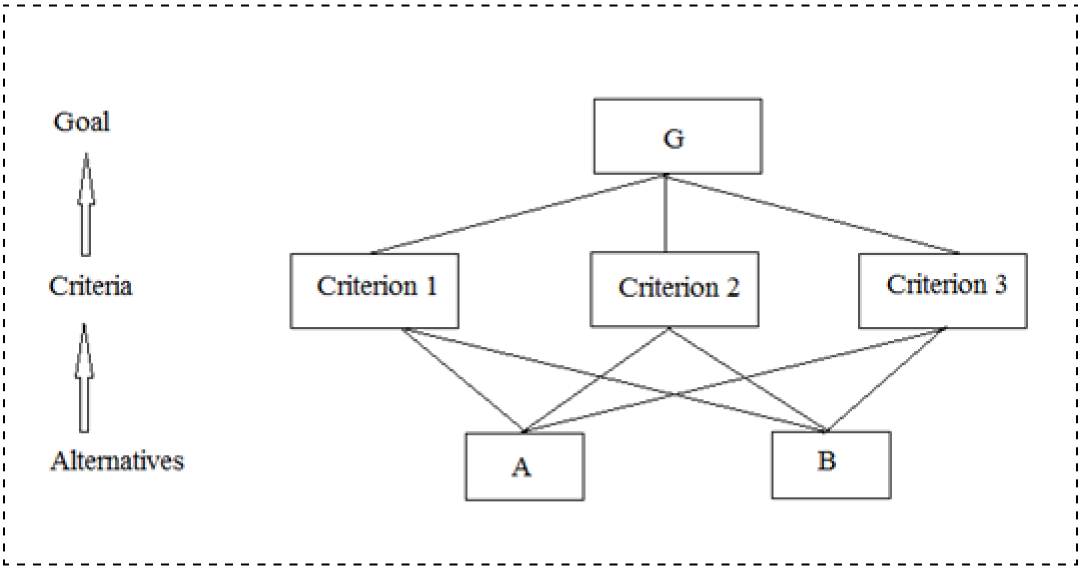


Figure 3.1.1: A simple hierarchical model

AHP method is very common and one of the most applicable methods of multi-criteria analysis (MCA). There are many applications of AHP in various fields in the literature. Aşchilean et al. (2017) used AHP method in the field of water supply in towns to choose the technology of pipe rehabilitation in water distribution systems. Hillerman et al. (2017) presented a model to analyse the suspicious claims data from healthcare providers with the use of different clustering algorithms, and applied AHP multicriteria method for prioritizing the identified suspect entities for subsequent auditing. AHP model provided rational criteria for futher investigation. Erdogan et al. (2017) used AHP method for decision making in construction management. Dong and Cooper (2016) proposed an orders-of-magnitude AHP (OM-AHP) based ex-ante supply chain risk assessment model, to allow the comparison of the tangible and intangible elements that influence supply chain risks. Gürcan et al. (2016) proposed AHP method to the third party logistic (3PL) provider selection problem. According to the AHP results, best alternative for 3PL provider is determined. Dweiri et al. (2016) developed a decision support model for supplier selection based on AHP using a case of automotive industry in Pakistan. Elia et al. (2016) used AHP to provide decision makers with quantitative knowledge for more efficiently designing Augmented Reality (AR) applications in manufacturing. Balo and Şağbanşua (2016) used AHP to decide the best solar panel for the photovoltaic system design. Riahi and Moharrampour (2016) applied AHP to find the best strategy in which organizations could use to develop resource management and analyzing business situations. Boujelbene and Derbel (2015) used AHP method for the performance analysis of public transport operators in Tunisia. Lee and Lee (2015) used AHP method to identify the policy priorities for creative tourist industry in Korea. Oddershede et al. (2015) applied AHP to assess the importance of Information and Communication Technology (ICT) support at primary school. Gdoura et al. (2015) proposed a combination of geospatial and AHP to locate and rank suitable sites for groundwater recharge with reclaimed water. Agarwal et al. (2014) applied AHP method for sustainable supplier selection through social parameters. Khanmohammadi and Rezaeiahari (2014) proposed AHP based metalearning algorithm to determine the suitable supervised classification algorithm for develoing clinical decision support system. Rahman et al. (2013) used AHP method for the determination of factors affecting RFID adoption in Chinese manufacturing firms. Xu (2012) proposed AHP method, and presented ERP sandtable simulation evaluation to examine how to make a decision using AHP. Peng (2012) proposed AHP method to assess and choose the logistics outsourcing service suppliers.

A scale of numbers is used to make comparisons between the elements with respect to the criterion. Table 3.1.1shows the scale (Saaty, 2008):

Table 3.1.1: The Fundamental Scale of Absolute Numbers

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

There are four steps to get the ranking of the alternatives. Fistly, the problem is constructed. Next, scores are calculated on the basis of the pairwise comparisons provided by the user. There is no need to get a numerical judgement from the decision maker; instead a relative verbal appreciation is enough. The remaining steps are consistency check and sensitivity analysis. They are both optional but recommended to confirm the robustness of the results. The consistency check is used in all methods based on pairwise comparisons like AHP. All comparisons are positive. The reason comparisons on the main diagonal are 1 is that a criterion is compared with itself (Ishizaka and Nemery, 2013).

If we wish to compare a set of n attributes pairwise according to their relative importance weights, where the attributes are donated by $a_{1,}a_{2,} \ldots , a_n$and the weights are donated by $w_1, w_2, \ldots, w_n$, then the pairwise comparison can be represented by questionnaires with subjective perception as (Tzeng and Huang, 2011):

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

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 $a_{ij} \cong w_i/w_j$.
Let a weight matrix be represented as:

$$\begin{matrix} & & w_1 \cdots w_j \;\; \cdots w_n \end{matrix}$$

$$W = \begin{matrix} w_1 \\ \vdots \\ w_i \\ \vdots \\ w_n \end{matrix} \begin{bmatrix} {}^{w_1}/_{w_1} & \cdots & {}^{w_1}/_{w_j} & \cdots & {}^{w_1}/_{w_n} \\ \vdots & & \vdots & & \vdots \\ {}^{w_i}/_{w_1} & \cdots & {}^{w_i}/_{w_j} & \cdots & {}^{w_i}/_{w_n} \\ \vdots & & & & \vdots \\ {}^{w_n}/_{w_1} & \cdots & {}^{w_n}/_{w_j} & \cdots & {}^{w_n}/_{w_n} \end{bmatrix} \quad (2)$$

By multiplying W and w yield

$$W = \begin{matrix} & w_1 & \cdots w_j & \cdots & w_n \\ \begin{matrix} w_1 \\ \vdots \\ w_i \\ \vdots \\ w_n \end{matrix} & \multicolumn{4}{c}{\begin{bmatrix} w_1/w_1 & \cdots & w_1/w_j & \cdots & w_1/w_n \\ \vdots & & \vdots & & \vdots \\ w_i/w_1 & \cdots & w_i/w_j & \cdots & w_i/w_n \\ \vdots & & & & \vdots \\ w_n/w_1 & \cdots & w_n/w_j & \cdots & w_n/w_n \end{bmatrix}} \end{matrix} \begin{bmatrix} w_1 \\ \vdots \\ w_i \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ \vdots \\ w_i \\ \vdots \\ w_n \end{bmatrix} \tag{3}$$

Or

$$(W - nI)*w = 0 \tag{4}$$

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

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

$$CI = (\lambda_{max} - n)/ (n-1) \tag{5}$$

Where λ_{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:

$$CR = \frac{CI}{RI} \tag{6}$$

Where rational index (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. The RI with respect to different size matrices shown in Table 3.1.2.

Table 3.1.2: The Rational Index for different size of Matrices

Number of elements (n)	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

The CR should be under 0.1 for a reliable result.

3.2 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

One of the multi-criteria decision-making approach, TOPSIS was developed by Hwang and Yoon in 1981. TOPSIS stands for the first letters of “Technique for Order Preference by Similarity to Ideal Solution”. The main idea of TOPSIS is that the best solution is the one which has the shortest distance to the ideal solution (Hwang and Yoon, 1981; Lai et al., 1994; Yoon 1980). As shown in Figure 3.2.1, where both criteria are to be maximized; alternative A is closer to the ideal solution than B and further from the negative-ideal solution if the criteria weights are equivalent (Ishizaka and Nemery, 2013).

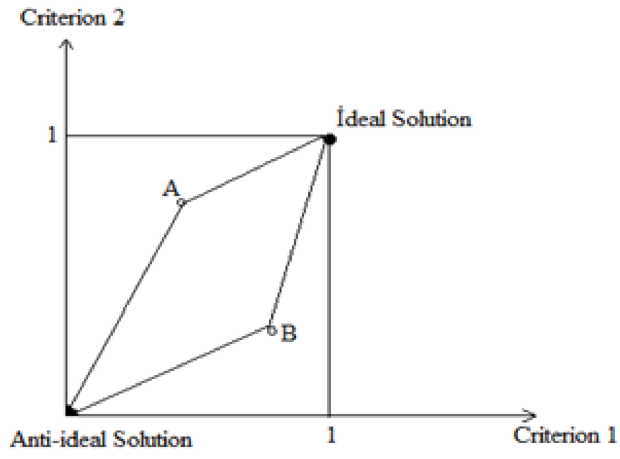


Figure 3.2.1: TOPSIS Method

Akbas and Bilgen (2017) developed a hybrid fuzzy Quality Function Deployment (FQFD) and TOPSIS model to choose the ideal gas fuel at wastewater treatment plant in Turkey. Kım (2016) used TOPSIS co compare port competitiveness among a sample of ports in Korean and China. Zhou et al. (2016) proposed vague TOPSIS method to choose the best alternative in project management. Wang (2014) proposed fuzzy TOPSIS method to assess financial performance of Taiwan container shipping companies. Zheng-Xin Wang and Yan-Yu Wang (2014) proposed an improved TOPSIS method for the Evaluation of the provincial competitiveness of the Chinese high-tech industry. Du et al. (2014) applied TOPSIS method for the evaluation of node importance in complex Networks. Zhu et al. (2014) proposed TOPSIS method to assess quality credit of the enterprises s in Chinese market. Iç (2014) developed Design of Experiment and TOPSIS method (DoE–TOPSIS) to evaluate the ranking of credit applicant companies. Bulgurcu (2012) applied TOPSIS method for financial performance evaluation of technology firms in Istanbul Stock Exchange market.

Although many applications of TOPSIS method is available in literature, a very large use of integrated methods with TOPSIS is used. Gupta and Barua (2017) applied fuzzy TOPSIS method for the selection of suppliers among Small and Medium Enterprises on the basis of their green innovation ability. Morteza et al. (2016) proposed an evaluation model based on the analytic network process (ANP) and TOPSIS, to select the optimal tourism site in the Integrated Coastal Zone Management in a fuzzy environment. Sánchez-Lozano et al. (2016) aimed to select best place in the coast of Murcia in the southeast of Spain to site build solar photovoltaic farms using TOPSIS-ELECTRE Tri methods. Kermani et al. (2016) applied TOPSIS method and genetic algorithm to develope a novel centrality measure (Sociability Centrality) for social networks. Mir et al. (2016) used TOPSIS and VIKOR methods in a multi criteria decision analysis to build an optimized municipal solid waste management model.

The TOPSIS method consists of five calculation steps. After gathering the performances of the alternatives on the different criteria, these performances are normalized in the following step. Then the normalized scores are weighted and distances to an ideal and anti-ideal point are calculated. In the final step, the closeness is given by the ratio of these distances. More detailed explanation of these five steps is given below (Ishizaka and Nemery, 2013).

The performances of m alternative i with respect n criteria j are collected in a decision matrixA = (a_{ij}) where i = 1, ..., m and j = 1, ... , n.

$$\boldsymbol{A_{ij}} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \quad (7)$$

Step 1: Construct normalized decision matrix using the formula given as:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \quad (8)$$

The performances of different criteria are normalized to be able to compare the measure on different units.

Step 2: Construct the Weighted Normalized Decision Matrix

A weighted normalized decision matrix is constructed by multiplying the normalized scores r_{ij} by their corresponding weights w_i :

$$v_{ij} = w_i * r_{ij} \tag{9}$$

$$\boldsymbol{V} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_n r_{1m} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_n r_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ \vdots & \vdots & \cdots & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_m r_{mn} \end{bmatrix} = \begin{bmatrix} v_{11} & v_{12} & \dots & v_{1n} \\ v_{21} & v_{22} & \dots & v_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \vdots & \vdots & \dots & \vdots \\ v_{m1} & v_{m2} & \dots & v_{mn} \end{bmatrix} \tag{10}$$

Step 3: Determine Ideal and Negative-Ideal Solutions

The weighted scores will be used to compare each action to an ideal and negative ideal virtual action.

For ideal action:

$$A^* = \{max_i\, v_{ij} \mid j = 1, \dots, n;\, i = 1, \dots, m\} \tag{11}$$

$A^* = \{v_1^*, v_2^*, \dots, v_n^*\}$ maximum value of each column of *V*.

And for the negative ideal action:

$$A^- = \{min_i v_{ij}\} \tag{12}$$

$A^- = \{v_1^-, v_2^-, \dots, v_n^-\}$ minimum value of each column of V.

Step 4: Calculate the Separation Measure:
For ideal action:

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \tag{13}$$

For the negative ideal action:

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{14}$$

Step 5 : Calculate the Relative Closeness Coefficient to the Ideal Solution:

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \tag{15}$$

The closeness coefficient is always between 0 and 1, where 1 is the preferred action. If an action is closer to the ideal than the negative-ideal, then C_i^* approaches 1, where if an action is closer to the negative ideal than to the ideal, C_i^* approaches 0. A set of alternatives can now be preference ranked according to the descending order of C_i^*.

3.3 Integrating AHP – TOPSIS Methodologies

Analytical Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are used to weight the criteria and outrank of the EVCS alternatives, respectively. The steps of the proposed method is illustrated in the Figure 3.3.1.

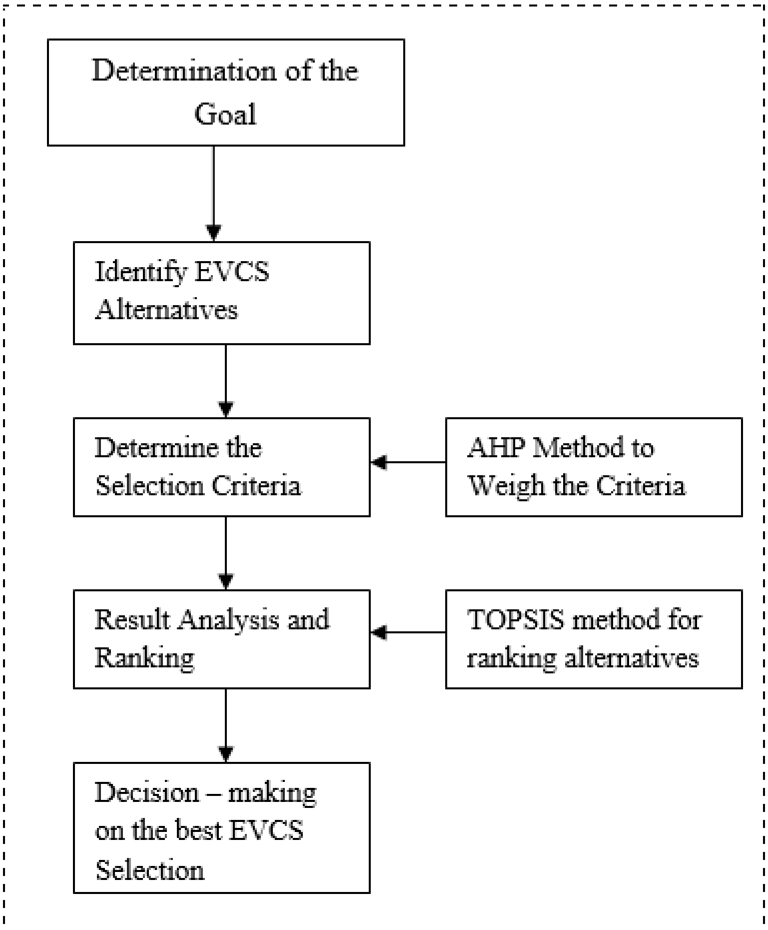


Figure 3.3.1: Steps of the integrated AHP – TOPSIS methodologies

In the literature there are many studies that use the integration of AHP and TOPSIS methods in various areas.

Sindhu et al. (2017) proposed hybrid combination of AHP and TOPSIS methods to choose optimal sites for solar farms and applied it to India. According to the sensitivity analysis effective and efficient results were yielded based on proposed method.

Karahalios (2017) combined AHP and TOPSIS to decide a cost-benefit decision-making tool, which would be applicable for the ship operators. Although a case study was carried out to validate the proposed method, the methodology should be tested with more applications.

Alizadeh et al. (2016) examined to choose the right approach for alunite beneficiation. Alunite is the most important nonbauxite resource for alümina. For this purpose, Delphi Analytical Hierarchy Process (DAHP) was used to weight selection criteria and Fuzzy TOPSIS approach was applied to decide the most profitable candidates.

Prakash and Barua (2015) used fuzzy AHP and fuzzy TOPSIS for the identification and ranking the solutions of reverse logistics (RL) adoption in electronics industry to overcome its barriers. Fuzzy AHP is used to obtain weights of the barriers as criteria by pairwise comparison and final ranking of the solutions of RL adoption is obtained by applying fuzzy TOPSIS. An empirical case of Indian electronics industry was carried out to demonstrate the applicability of the proposed method. Sensitivity analysis proves the effectiveness of the method.

Sekhar et al. (2015) focused on building a framework that prioritizes potential alternatives and suggest a critical indicator of intellectual capital (IC). To do this, a Delphi-AHP-TOPSIS methodology was proposed and a case study was carried out in Small Medium Enterprises (SMEs) manufacturing unit located in central northern part of India. According to the results SMEs manufacturing unit directors may make use of the findings of the paper as base for optimal investment of funds in IC indicators.

Zare et al. (2015) used Strength Weaknesses-Opportunities-Threats (SWOT) analysis for the electricity supply chain in north-west Iran. An integrated AHP and fuzzy TOPSIS methods are presented to rank the SWOT factors for the proposed electricity supply chain. According to the results the proposed method is efficient for planning and decision-making in electricity supply chain.

Zaidan et al. (2015) applied an integrated AHP and TOPSIS method for the assesment and selection of open-source EMR software packages.

Kusumawardani and Agintiara (2015) presented fuzzy AHP and TOPSIS method for the selection of human resources manager and applied it to a prominent telecommunication company in Indonesia.

Oztaysi (2014) proposed an integrated AHP and Grey TOPSIS method to select the Content Management System (CMS) and applied it in a Turkish foreign trade company. Sensitivity analysis results show the effectiveness and applicability of the proposed method.

Avika et al. (2014) proposed a Kano model, fuzzy-AHP, and M-TOPSIS-based technique to assign the tasks to the workstations in to satisfy the part demand, revenue generated and environmentally friendly disassembly. The proposed method applied to an example and the results shows the robustness of the method.

Beikkhakhian et al. (2015) applied interpretive structural model (ISM) to assess agile suppliers selection criteria used fuzzy AHP and TOPSIS methods to rank the suppliers. The study shows that the integrated model increases the efficiency of the results.

Taylan et al. (2014) evaluated the risk of construction projects and used fuzzy AHP and TOPSIS for the selection of them. According to the results the proposed methodologies are able to evaluate the overall risks of construction projects.

Patil and Kant (2014) presented fuzzy AHP and TOPSIS to determine the solutions of Knowledge Management (KM) adoption in Supply Chain (SC) to overcome its drawback. The proposed method yields effective results according to the empirical case study analysis of an Indian hydraulic valve manufacturing organization.

Zyoud et al. (2016) integrated fuzzy AHP with fuzzy TOPSIS to identify the key options among a set of options to decrease water losses in water distribution systems of developing countries. The proposed method yields effective results when dealing with complicated issues.

Tyagi et al. (2014) used AHP and TOPSIS method to choose a best alternative to improve electronic supply chain management (e-SCM) performance of Indian automobile industry. The result of the study allows managers to take better decisions when developing strategies in improving e-SCM performance of an organization.

Mandic et al. (2014) analyzed the financial parameters of Serbian banks through the application of the fuzzy AHP and TOPSIS methods. The outcome of the study is consistent to make decision based on selected financial indicators.

Yu et al. (2013) assessed the index system of urban road intersections traffic congestion by AHP method and the traffic status of intersections was assessed and decided by TOPSIS method. The proposed method was verified by an actual example about the urban road intersection traffic congestion. The results show that the combined method is appropriate for the given problem.

Vinodh et al. (2014) aims to identify the best method for recycling plastics among the various plastic recycling processes using integrated hybrid fuzzy AHP and TOPSIS methods. Because the problem involves complex decision variables, the proposed method is able to solve it.

Awasthi and Chauhan (2012) developed an integrated Affinity Diagram, AHP and fuzzy TOPSIS method for sustainable city logistics planning. The proposed method is easy to apply for selecting sustainable city logistics initiatives for cities and the method is able to produce solutions under limited quantitative information.

Amiri (2010) analyzed alternative projects for oil-fields development using AHP and fuzzy TOPSIS techniques. The proposed method applied to National Iranian Oil Company show the utilization of the model for the project selection problems.

Table 3.3.1 illustrates the brief review of AHP and TOPSIS literature studies.

Table 3.3.1: AHP and TOPSIS Literature Survey

Publication Author(s) Publishing Year	Applied Methods	Considered Issues and Problems
Sindhu et al. (2017)	AHP and TOPSIS	An integrated Multi Criteria Evaluation (MCE) methods for selecting appropriate solar farm site: Case Study of India.
Karahalios (2017)	AHP and TOPSIS	Application of a multiple-criteria decision making approach to determine a cost-benefit decision-making tool: Case Study of the USA.
Alizadeh et al. (2016)	DAHP and Fuzzy TOPSIS	Selecting the right approach for alunite beneficiation using multi attribute decision making model.
Prakash and Barua (2015)	Fuzzy TOPSIS and Fuzzy AHP	Identifiying and ranking the solutions of reverse logistics (RL) adoption in electronics industry by fuzzy AHP and TOPSIS: An empirical case of Indian electronics industry.
Sekhar et al. (2015)	Delphi-AHP-TOPSIS	Ranking potential alternatives: Case study of central northern part of India.
Zare et al. (2015)	SWOT, AHP and fuzzy TOPSIS	Analysing the electricity supply chain in north-west Iran.
Zaidan et al. (2015)	AHP and TOPSIS	An integrated multi-criteria decision-making approach for EMR software packages.
Kusumawardani and Agintiara (2015)	Fuzzy AHP and TOPSIS	Selecting of human resources manager. Case study of a company in Indonesia.
Oztaysi (2014)	AHP and Grey TOPSIS	Application of a multi criteria decision making model for the selection of information technology for a company in Turkey.
Avika et al. (2014)	Kano model, fuzzy-AHP, and M-TOPSIS-based technique	Assigning the task to the workstations using a hybrid combination of Kano model, fuzzy-AHP, and M-TOPSIS-based technique.

Beikkhakhian et al. (2015)	Interpretive structural model (ISM), fuzzy AHP and TOPSIS	Evaluating the supplier selection criteria using ISM and ranking the suppliers by fuzzy AHP and TOPSIS
Taylan et al. (2014)	Fuzzy AHP and TOPSIS	Risk assesment of the construction Project by fuzzy AHP and TOPSIS.
Patil and Kant (2014)	Fuzzy AHP and TOPSIS	Identfying the solutions of Knowledge Management (KM) adoption in Supply Chain (SC): Empirical case study analysis of an Indian manufacturing organization
Zyoud et al. (2016)	Fuzzy AHP and TOPSIS	Application of multi criteria decision analysis (MCDA) approaches for water loss management.
Tyagi et al. (2014)	AHP and TOPSIS	Selecting information technology (IT) for to improving electronic supply chain management (e- SCM) performance: Case study of India.
Mandic et al. (2014)	Fuzzy AHP and TOPSIS	Combining two methods of multi-criteria decision-making methods to examine the parameters of Serbian banks.
Yu et al. (2013)	AHP and TOPSIS	Evaluation of urban road intersections traffic congestion based on multi criteria decision making.
Vinodh et al. (2014)	Fuzzy AHP and TOPSIS	Selection of the best recycling method by multiple criteria decision-making (MCDM).
Awasthi and Chauhan (2012)	Affinity Diagram, AHP and fuzzy TOPSIS	Integrating Affinity Diagram, AHP and fuzzy TOPSIS for sustainable city logistics planning.
Amiri (2010)	AHP and fuzzy TOPSIS	Project selection for oil-fields development by using the AHP and fuzzy TOPSIS methods.

Based on the studies in literature, we have selected AHP-TOPSIS methodologies due to its following strengths: The information requirements of the proposed framework are divided into a hierarchy to simplify information input and to focus on a small area of the large problem. A strong agreement among experts, as measured by the AHP with CR values, can reduce the uncertainty of the proposed model. The AHP method is very common and one of the most applicable methods of multi-criteria analysis (MCA) due to its simplicity. TOPSIS is popular and simple in concept however, it is often criticized because of its inability to deal with uncertainty. To overcome this issue, AHP is combined with TOPSIS. AHP-TOPSIS is a methodology which allows decreasing the uncertainty and the information loss in group decision making and thus, provides a robust solution to the problem.

3.4 Mathemetical 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 objective function mainly concentrates on minimizing the cost or meeting the drives demand.

Liang et al. (2012) presented a planning model which selects the charging station locations with the objective of minimizing the investment cost of charging stations and users' wastage cost on the way to the charging station. The proposed method was applied to a case study which showed that the model was practical.

Meng and Kai (2011) 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. This makes the calculation process more simple and clear with strong feasibility and practicality.

Nakamura et al. (2016) presented a 2-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.

He et al. (2015) 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. However, the proposed method ignores the possible congestion occurring at public charging stations, numerical examples shows robustness of the model.

Li et al. (2016) 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. According to the results the presented model is subject to a number of major factors, including geographic distributions of cities, vehicle range, and deviation choice, and is sensitive to the types of charging station sites.

Yang and Hu (2017) aims 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.

Wu and Sioshansi (2017) presented a model to optimize the location of 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.

Awasthi et al. (2017) 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.

Alegre et al. (2017) 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. The proposed algorithm, based on a genetic algorithm, has a good performance since it gets some planning solutions which reduces the cost of losses. According to the results the developed algoritm is applicable and the use of GIS is necessary to get the demand in a certain area according to the surface of the area.

Shi and Lee (2015) formulated a multi-objective matematical 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. Strenghten Pareto Evolutionary Algorithm – II was used to solve the problem. Case study result shows the feasibility of the algorithm to solve the multi-objective model by contrast to other single-objective algorithm (Genetic Algorithm).

Xiong, Yanhai, et al. (2015) discussed the charging station placement problem (CSPL) and formulated it as a bilevel optimization problem and then turned it to a single level problem. An algorithm called OCEAN was used to assign the charging station to optimal loations. A heuristic algorithm called OCEAN-C was presented to improve OCEAN. The proposed method has better performsnce compared to other baseline methods according to the experimental results.

Liu et al. (2013) identified the optimal location of charging stations by a two-step screening method then a mathematical model was formulated to minimize the total costs assosiated with EV charging stations and to make the optimal sizing of EV charging stations. The model was solved by a modified primal-dual interior dual algorithm. The simulation results indicates the effectiveness and robustness of the proposed algorithm.

Jia et al. (2012) 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. The results justify the effectiveness and applicability of the model.

Chen et al. (2013) built a mixed integer programming model to find the optimal location and number of electric vehicle charging stations in Seattle.

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 Kadıköy and Ataşehir, two districts of Istanbul, Turkey, has been selected to apply the provided model. Kadıköy is a large, populous, and cosmopolitan district of Istanbul on the northern shore of the Sea of Marmara as illustrated in Figure 4.1.1.The population of Kadıköy district, according to the 2014 census, is 482,571.The district of Kadıköy has an important position in terms of city transportation. Some main roads connecting the various districts of Istanbul pass through Kadıköy District. In the "Standard of Living Survey in Istanbul" held in 2015, Kadıköy took second place among all the districts.

Ataşehir is located at the junction of the Motorway 2 (O-2) and Motorway 4 (O-4) in the Anatolian part of Istanbul as illustrated in Figure 4.1.1.The population of Ataşehir district, according to the 2012 census, is 395,758.The population mainly consists of high income families. The area is appropriate for transportation by private car, because choices of public transport are very limited.

The high income level of the population of both Kadıköy and Ataşehir is an important factor to choose these two districts for locating charging station. Because EV use in Istanbul is already not prevalent, as it is an expensive technology compared to gasoline-powered vehicle. The other reason is Kadıköy and Ataşehir are situated in central locations, therefore accessibility is relatively easy and people are eager to spend their leisure time in or around these districts.

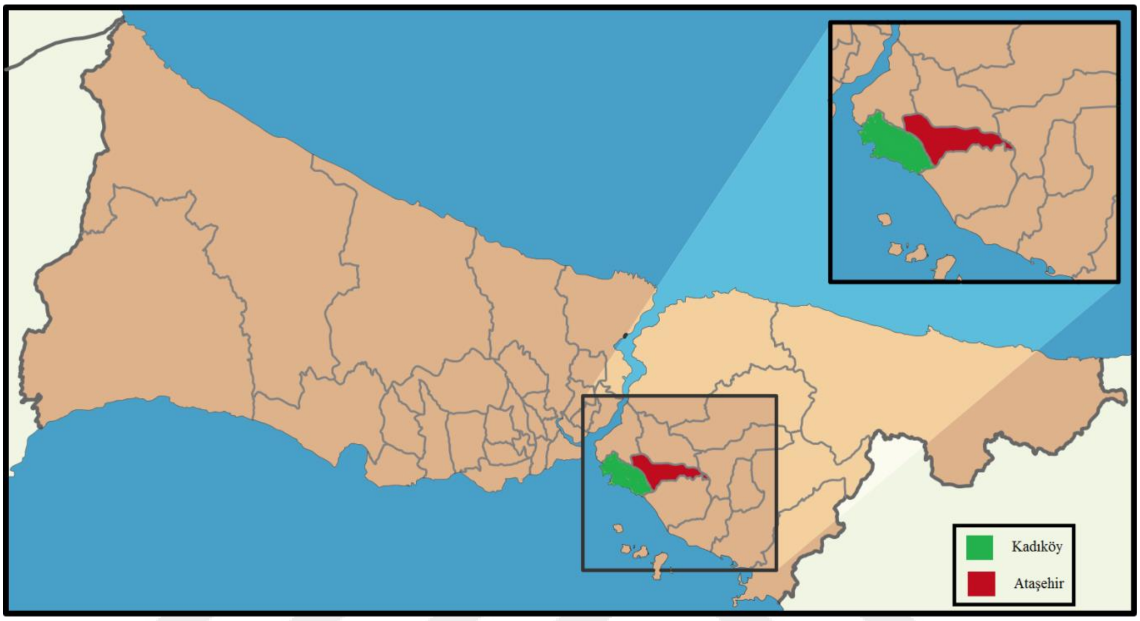


Figure 4.1.1: Location of Kadıköy and Ataşehir in Istanbul

4.2 Implementation

In Istanbul, it is very common for people to spend their leisure time in shopping malls, cultural centers. In addition to shopping places, these places provide many places such as performance halls for concerts, theatre and exhibition hall, cafes and restaurants within them. For this reason, we decided to identify shopping malls and cultural centers in Kadıköy and Ataşehir to locate Level II charging stations. Our alternatives are (Figure 4.2.1):

A1: Brandium Shopping Mall

A2: Bulvar 216

A3: Caddebostan Cultural Center

A4: Icerenkoy Carrefour

A5: Kozzy Shopping Mall

A6: Novada Shopping Mall

A7: Optimum Outlet

A8: Palladium Shopping Mall

A9: Tepe Nautilus Shopping Mall

A10: Water Garden Istanbul

Table 4.2.1: Car parking Capacity and Operating Hours of Alternatives

	Car Parking Capacity	Operating Hours (Monday - Sunday)
Brandium Shopping Mall	1600	10:00am - 22:00 pm
Bulvar 216	600	10:00am - 22:00 pm
Caddebostan Cultural Center	150	13:00am - 21:00 pm
Icerenkoy Carrefour	2884	10:00am - 22:00 pm
Kozzy Shopping Mall	259	10:00am - 22:00 pm
Novada Shopping Mall	-	10:00 am- 22:00 pm
Optimum Outlet	1569	10:00am - 22:00 pm
Palladium Shopping Mall	2500	09:00am - 22:00 pm
Tepe Nautilus Shopping Mall	2700	10:00am - 22:00 pm
Water Garden Istanbul	1835	10:00am - 22:00 pm

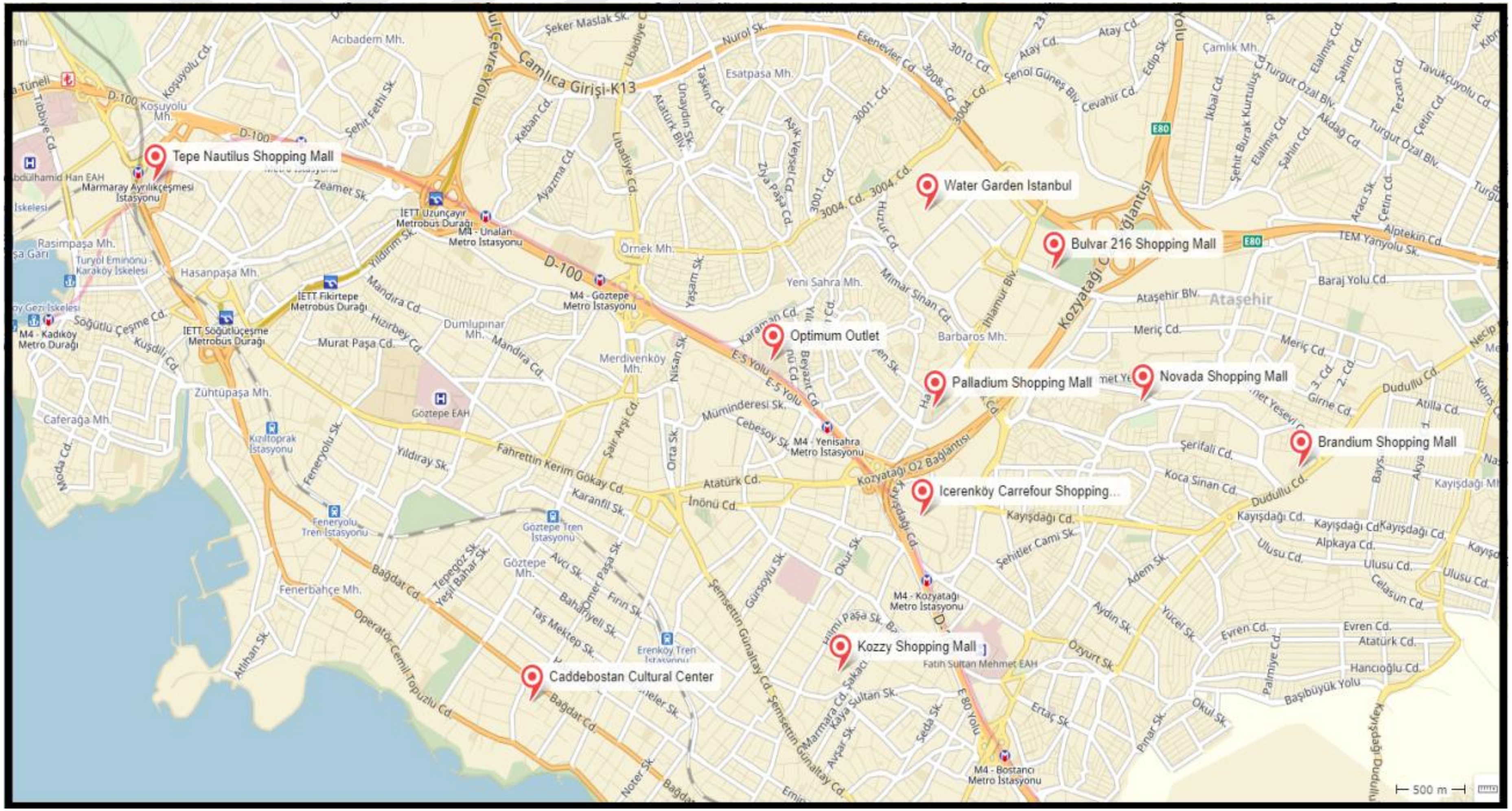


Figure 4.2.1: Alternative Points

In literature some studies are concentrated on MCDM methodologies to find out optimal locations of EVCS. Many criteria are considered to make a good decision in this process.

Efthymiou et al. (2012) 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.

Meng et al. (2013) proposed fuzzy analytic hierarchy process (AHP) method to evaluate the EVCS location problem. They constructed a judgment hierarchy divided into 3 levels, including 4 first-class factors of evaluation and 14 second-class factors of evaluation. Four first-class factors are nature, management, public facilities and economic. Sub-factors of nature factor are weather condition, geological conditions, hydrologic conditions; sub-factors of management factor are government planning, policy environment, distribution of electric vehicles around, traffic conditions, land use conditions; sub-factors of public facilities factor are electricity grid situation, station harmonic pollution problem, fire and explosion prevention; sub-factors of economic factor are total investment cost and annual operation cost.

Guo and Zhao (2015), discussed multi-criteria decision-making (MCDM) method to examine some subjective but significant criteria for EVCS location selection. Fuzzy TOPSIS method was used to select the optimal EVCS location. 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. By proposing various sub-criteria and evaluating each of them makes the study more accurate and yields consistent results.

Liu et al. (2012) used the Delphi method (Delphi), grey statistics method of decision-making and analytic hierarchy process to assess the location of charging stations. They integrated Grey Analytic Hierarchy Process (GAHP) and Delphi method to build a new evaluation method. This integrated method is useful to find a solution to the problem because there are many influencing factors, multiple levels and gray information and so on in electric car battery charging station's evaluation. They introduced four criteria which are traffic convenience, economy, technical feasibility and influence rationality to evaluate EVCS candidates.

Tang et al. (2013) used Voronoi Diagram to divide the zone, in which a charging station is built and then proposed fuzzy analysis and Analytical Hierarchy Process (AHP) 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.

Xu et al. (2013) 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.

Jia et al. (2012) formulated the mathematical expression of each factors 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.

Yağcıtekin et al. (2014) 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.

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 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.

Our criteria are:

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 hierarchy is configured and the criteria are calculated by using Super Decision 2.0.8 Programs which is a decision support software that implements the AHP and ANP (Fiure 4.2.2 and Table 4.2.2). Overall composite weight of the alternatives is get after the calculations in Super Decision 2.0.8 Programs.

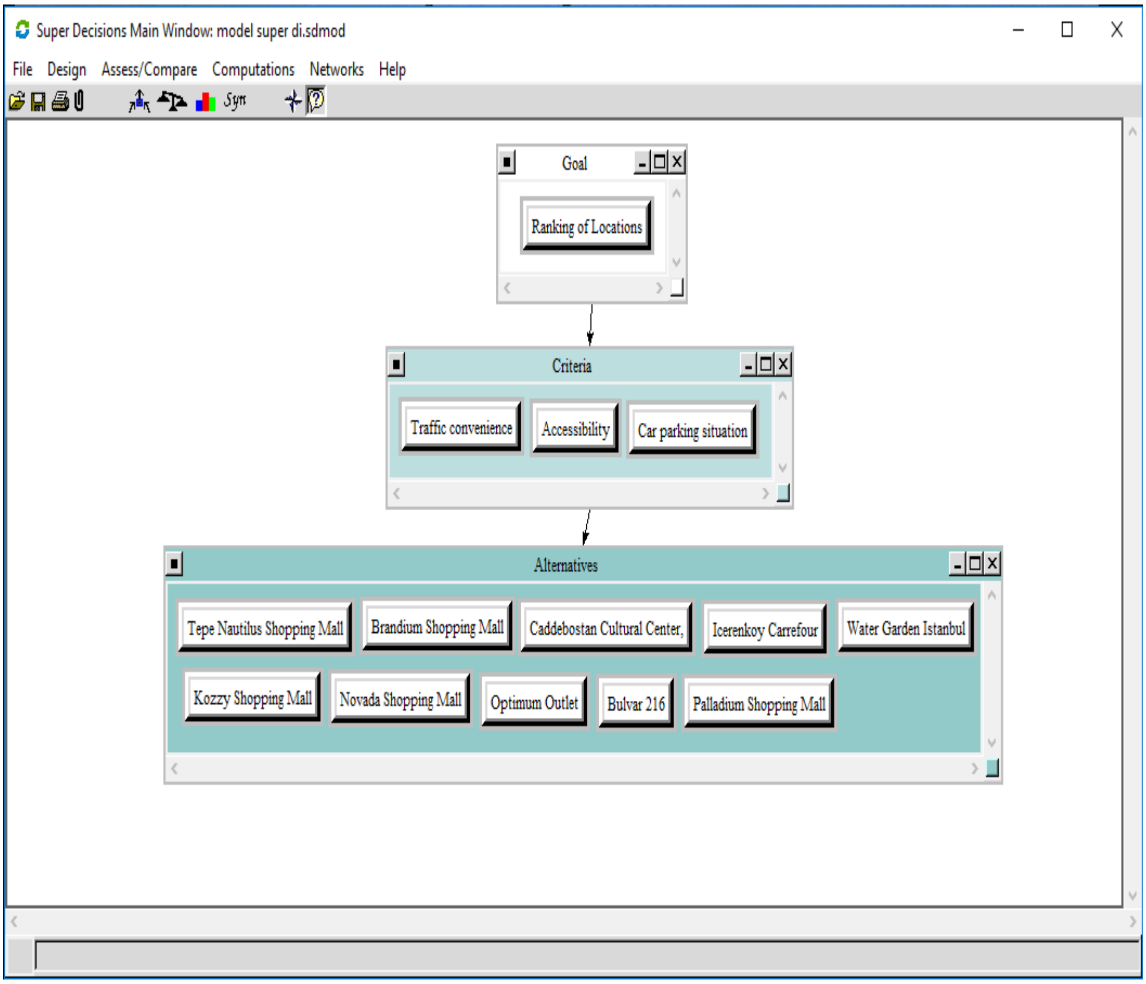


Figure 4.2.2: Configuring the hierarchy with Super Decision 2.0.8 Programs

Table 4.2.2: 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 4.2.2. It is obtained that car parking situation of the shopping malls is the most important criterion for EV drivers according to priotiry 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 4.2.3: Comparison of Alternatives with respect to Accessibility

C1	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	Priority	Inconsistency Ratio
A1	1.0	2	4	0.16	4	2	0.16	1.0	0.3	2	0.075	CR = 0.04854
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 4.2.3. Optimum Outlet is the most preferable shopping mall according to priority value which is 0.256. Then Icerenkoy Carrefour ranks with the value of 0.226. The priority value of Tepe Nautilus is 0.165, Brandium is 0.075, Palladium Shopping Mall is 0.063, Water Garden Istanbul is 0.059, Bulvar 216 is 0.056, Novada Shopping Mall is 0.049, Kozzy Shopping Mall is 0.025 and Caddebostan

Cultural Center is the least preferable place with the value of 0.023. The value of inconsistency ratio provides consistent results.

Table 4.2.4: Comparison of Alternatives with respect to Car Parking Situation

C2	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	Priority	Inconsistency Ratio
A1	1.0	2	5	0.5	4	2	0.33	0.5	1.0	0.2	0.085	CR = 0.04830
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 4.2.4. Water Garden Istanbul is the most preferable shopping mall because it has the highest priority value. Caddebostan Cultural Center is the least preferable place because it has the lowest priority value. Palladium Shopping Mall takes second place, Icerenkoy Carrefour ranks third, then comes Optimum Outlet, Brandium takes next place, Bulvar 216, Tepe Nautilus Shopping Mall, Novada Shopping Mall, and Kozzy Shopping Mall ranks respectively. The value of inconsistency ratio gives reliable results.

The comparison of alternatives with respect to traffic convenience is illustrated in Table 4.2.5. When it is ranked in the order of importance Brandium comes first, then Palladium Shopping Mall, Water Garden Istanbul, Novada Shopping Mall, Bulvar 216, Tepe Nautlus Shopping Mall, Icerenkoy Carrefour, Optimum outlet, Kozzy Shopping Mall and Caddebostan Cultural Center come. The value of inconsistency ratio is 0.09990 which means it yields reliable results.

Table 4.2.5: Comparison of Alternatives with respect to Traffic Convenience

C3	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	Priority	Inconsistency Ratio
A1	1.0	5	5	4	5	4	4	1.0	3	2	0.230	CR = 0.09990
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	

We compute the overall composite weight of each alternatives choice based on the weight of level 1 and level 2. The overall weight is just normalization of linear combination of multiplication between weight and priority vector.

A1=(0.319*0.075) + (0.558*0.085) + (0.121*0.230) = 0.0998

A2= (0.319*0.056) + (0.558*0.071) + (0.121*0.089) = 0.0690

A3 = (0.319*0.023)+ (0.558*0.028) + (0.121*0.026) = 0.0270

A4 = (0.319*0.226) + (0.558*0.121)+ (0.121*0.073) = 0.1491

A5 = (0.319*0.025) + (0.558*0.033)+ (0.121*0.028) = 0.0301

A6 = (0.319*0.049) + (0.558*0.055)+ (0.121*0.113) = 0.0605

A7 = (0.319*0.256) + (0.558*0.114)+ (0.121*0.060) = 0.1530

A8 =(0.319*0.063) + (0.558*0.139)+ (0.121*0.157) = 0.1175

A9 = (0.319*0.165) + (0.558*0.066)+ (0.121*0.076) = 0.0995

A10 =(0.319*0.059) + (0.558*0.282)+ (0.121*0.143) = 0.1942

Table 4.2.6: Overall composite weight of the alternatives

	Accessibility	Car parking situation	Traffic convenience	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

The composite weight of Brandium Shopping Mall is 0.0998, Bulvar 216 is 0.0690, Caddebostan Cultural Center is 0.0270, Icerenkoy Carrefour is 0.1491, Kozzy Shopping Mall is 0.0301, Novada Shopping Mall is 0.0605, Optimum Outlet is 0.1530, Palladium Shopping Mall is 0.1175, Tepe Nautilus Shopping Mall is 0.0995 and Water Garden Istanbul is 0.1942.

4.3 Ranking of the Alternatives

The performances of each candidate with respect to three criteria are shown in Table 4.2.6 which were obtained according to AHP calculations. After the calculations by using TOPSIS method the weighted normalized matrix is get (Table 4.3.1).

Table 4.3.1 Weighted normalized matrix

	Accessibility	Car parking situation	Traffic convenience
Weight	0.319	0.558	0.121
A1	0.059	0.123	0.075
A2	0.044	0.102	0.029
A3	0.018	0.040	0.008
A4	0.178	0.175	0.024
A5	0.019	0.047	0.009
A6	0.038	0.079	0.037
A7	0.201	0.165	0.019
A8	0.049	0.201	0.051
A9	0.130	0.095	0.025
A10	0.046	0.409	0.047

Determining ideal and negative ideal solution;

For ideal solution

$A^* = \{0.201 \;\; 0.409 \;\; 0.075\}$

For negative ideal solution

$A^{-} = \{0.018 \;\; 0.040 \;\; 0.008\}$

Calculation separation measures was shown in Table 4.3.2 and Table 4.3.3.

Table 4.3.2: The calculation of ideal distance

Alternative Locations	Accessibility	Car parking situation	Traffic convenience	Sum	S_i^*
A1	0.020	0.081	0	0.102	0.319
A2	0.024	0.093	0.002	0.120	0.347
A3	0.033	0.135	0.004	0.174	0.417
A4	0.00055	0.054	0.002	0.057	0.240
A5	0.033	0.130	0.004	0.168	0.409
A6	0.026	0.108	0.0014	0.136	0.369
A7	0	0.059	0.003	0.062	0.250
A8	0.023	0.043	0.0005	0.066	0.258
A9	0.005	0.098	0.002	0.105	0.325
A10	0.024	0	0.0008	0.024	0.157

Table 4.3.3: The calculation of negative ideal distance

Alternative Locations	Accessibility	Car parking situation	Traffic convenience	Sum	S_i^-
A1	0.0017	0.0068	0.0045	0.013	0.1141
A2	0.0006	0.0038	0.0004	0.0050	0.070
A3	0	0	0	0	0
A4	0.0256	0.018	0.0002	0.044	0.209
A5	0.000	0.0000	0.0000	0.0000	0.0074
A6	0.0004	0.0015	0.0008	0.0027	0.0526
A7	0.0337	0.0155	0.00012	0.0494	0.2223
A8	0.0009	0.0259	0.0018	0.0287	0.1696
A9	0.0125	0.0030	0.0002	0.0158	0.1258
A10	0.0008	0.1357	0.0014	0.1380	0.3715

Calculation of the relative closeness is shown in Table 4.3.4. According to C_i^* results, the best location is Water Garden Istanbul which has the highest C_i^* value and the worst location is Caddebostan Cultural Center which has the lowest C_i^* value.

Table 4.3.4: Closeness calculation

	S_i^-	S_i^*	C_i^*	Rank
Brandium Shopping Mall	0.1141	0.319	0.2633	6
Bulvar 216	0.070	0.347	0.1693	7
Caddebostan Cultural Center	0	0.417	0	10
Icerenkoy Carrefour	0.209	0.240	0.466	3
Kozzy Shopping Mall	0.0074	0.409	0.0178	9
Novada Shopping Mall	0.0526	0.369	0.1247	8
Optimum Outlet	0.2224	0.250	0.4707	2
Palladium Shopping Mall	0.1696	0.258	0.3963	4
Tepe Nautilus Shopping Mall	0.1258	0.325	0.2789	5
Water Garden Istanbul	0.3715	0.157	0.7016	1

4.4 Proposed Mathematical Formulation of the Problem

In our model, we aim to find the optimal number of charging stations by maximizingdrivers 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, installtion 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 $$\sum_{i=1}^{10} W_i X_i \quad (16)$$

Objective function (16) 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 $$\sum_{i=1}^{10} C_i X_i \leq B \quad (17)$$

The budget constraint set (17) provides the number of charging station to install. We can buy a certain number of charging station under a bugdet limit. For this reason, a budget is allocated to determine how many station to install. We consider costs as EVSE unit cost, installtion cost, operation and maintenance costs.

$$\sum_{i=1}^{10} X_i \leq K_i, \forall i \quad (18)$$

The constraint set (18) ensuresthat each alternative location has a certain capacity to install EVCS.

$$X_i \geq 0\ ,\forall i \qquad (19)$$

Constraint (19) ensures that the number of charging station to locate is equal or greater than 0.

Data Set:

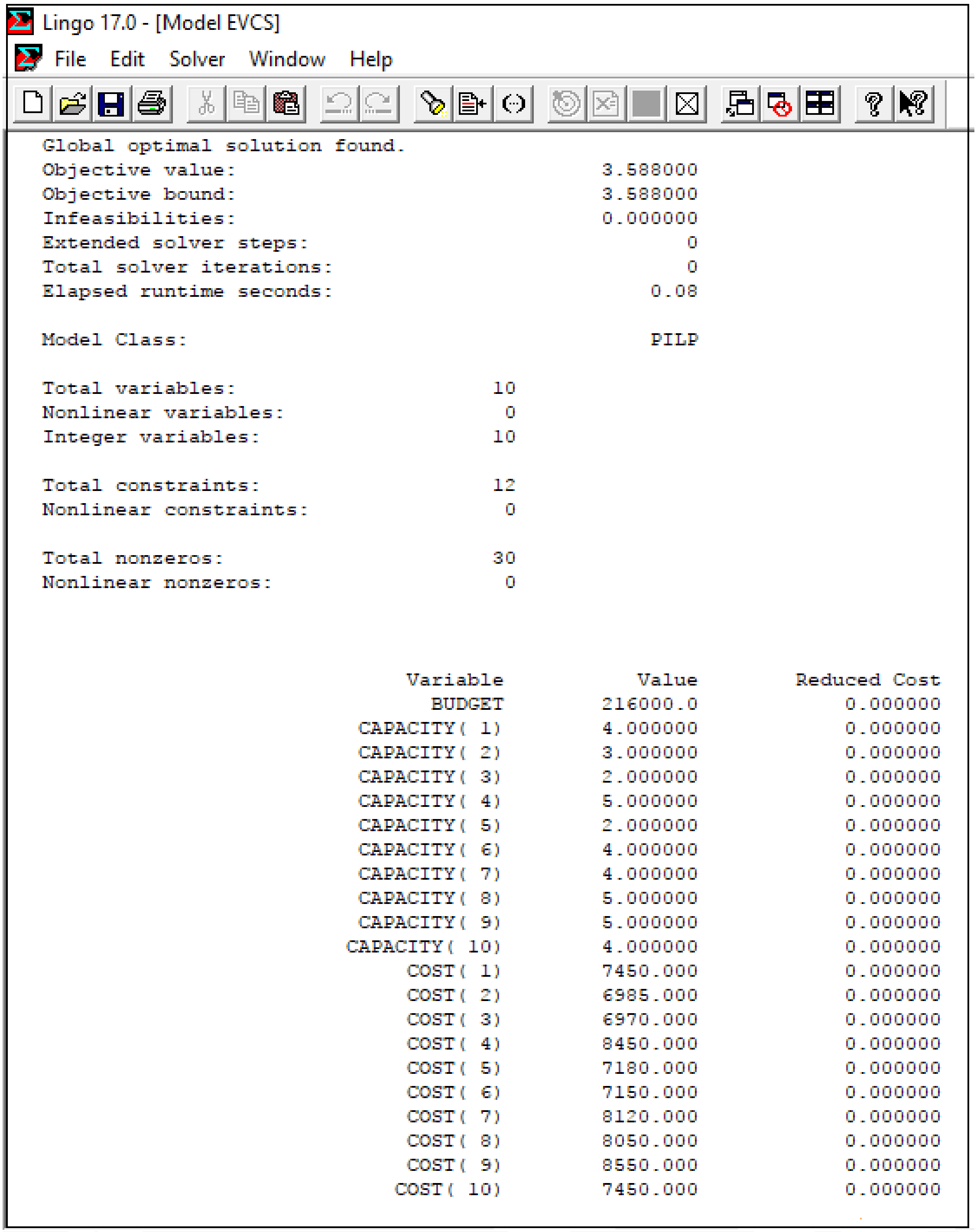
We obtained weights for each shopping mall by AHP calculations (Table 4.2.6: Overall composite weight of the alternatives). We considered EVSE unit cost, installtion cost, operation and maintenance costs for each shopping mall. We took average EVSE unit cost for Level II is as $3,209. Operation and maintenance cost and installation cost which includes trenching, supplying electrical sercive 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 4.4.1.

Total budget limit available to buy ECVS is $216000 and the capacity to be able to charge all the EVs in each of shopping mall is considered as follows (Table 4.4.1).

Table 4.4.1: Data Set

I	Weight (W)	Cost ($)	Capacity
Brandium Shopping Mall	0.0998	7,450	4
Bulvar 216	0.0690	6,985	3
Caddebostan Cultural Center	0.0270	6,970	2
Icerenkoy Carrefour	0.1491	8,450	5
Kozzy Shopping Mall	0.0301	7,180	2
Novada Shopping Mall	0.0605	7,150	4
Optimum Outlet	0.1530	8,120	4
Palladium Shopping Mall	0.1175	8,050	5
Tepe Nautilus Shopping Mall	0.0995	8,550	5
Water Garden Istanbul	0.1942	7,450	4

The model was solved in LINGO 17.0 Solver optimization tool. Thus, we have Figure 4.4.1.



```
Lingo 17.0 - [Model EVCS]
File  Edit  Solver  Window  Help

Global optimal solution found.
Objective value:                              3.588000
Objective bound:                              3.588000
Infeasibilities:                              0.000000
Extended solver steps:                               0
Total solver iterations:                             0
Elapsed runtime seconds:                          0.08

Model Class:                                      PILP

Total variables:                   10
Nonlinear variables:                0
Integer variables:                 10

Total constraints:                 12
Nonlinear constraints:              0

Total nonzeros:                    30
Nonlinear nonzeros:                 0


                         Variable           Value        Reduced Cost
                           BUDGET        216000.0            0.000000
                     CAPACITY( 1)        4.000000            0.000000
                     CAPACITY( 2)        3.000000            0.000000
                     CAPACITY( 3)        2.000000            0.000000
                     CAPACITY( 4)        5.000000            0.000000
                     CAPACITY( 5)        2.000000            0.000000
                     CAPACITY( 6)        4.000000            0.000000
                     CAPACITY( 7)        4.000000            0.000000
                     CAPACITY( 8)        5.000000            0.000000
                     CAPACITY( 9)        5.000000            0.000000
                    CAPACITY( 10)        4.000000            0.000000
                         COST( 1)        7450.000            0.000000
                         COST( 2)        6985.000            0.000000
                         COST( 3)        6970.000            0.000000
                         COST( 4)        8450.000            0.000000
                         COST( 5)        7180.000            0.000000
                         COST( 6)        7150.000            0.000000
                         COST( 7)        8120.000            0.000000
                         COST( 8)        8050.000            0.000000
                         COST( 9)        8550.000            0.000000
                        COST( 10)        7450.000            0.000000
```

WEIGHT(1)	0.9980000E-01	0.000000
WEIGHT(2)	0.6900000E-01	0.000000
WEIGHT(3)	0.2700000E-01	0.000000
WEIGHT(4)	0.1491000	0.000000
WEIGHT(5)	0.3010000E-01	0.000000
WEIGHT(6)	0.6050000E-01	0.000000
WEIGHT(7)	0.1530000	0.000000
WEIGHT(8)	0.1175000	0.000000
WEIGHT(9)	0.9950000E-01	0.000000
WEIGHT(10)	0.1942000	0.000000
X(1)	4.000000	-0.9980000E-01
X(2)	1.000000	-0.6900000E-01
X(3)	0.000000	-0.2700000E-01
X(4)	5.000000	-0.1491000
X(5)	0.000000	-0.3010000E-01
X(6)	0.000000	-0.6050000E-01
X(7)	4.000000	-0.1530000
X(8)	5.000000	-0.1175000
X(9)	4.000000	-0.9950000E-01
X(10)	4.000000	-0.1942000

Row	Slack or Surplus	Dual Price
1	3.588000	1.000000
2	235.0000	0.000000
3	0.000000	0.000000
4	2.000000	0.000000
5	2.000000	0.000000
6	0.000000	0.000000
7	2.000000	0.000000
8	4.000000	0.000000
9	0.000000	0.000000
10	0.000000	0.000000
11	1.000000	0.000000
12	0.000000	0.000000

Figure 4.4.1 Solution Report - LINGO

According to LINGO results we obtained optimal number of charging stations as illustrated in Table 4.4.2. Objective value is 3,58. The Solution Report shows the values of each variable that will produce the optimal value of the objective function. The reduced cost for any variable that is included in the optimal solution is always zero. In the Solution Report, slack/surplus is zero which means a constraint is completely satisfied as an equality. The Dual Price column describes the amount to which the value of the objective function would improve if the constraining value is increased by one unit.

Table 4.4.2: Number of Charging Station to be located to each shopping mall

I	Number of charging stations to be located (X_i)
Brandium Shopping Mall	**4**
Bulvar 216	**1**
Caddebostan Cultural Center	**0**
Icerenkoy Carrefour	**5**
Kozzy Shopping Mall	**0**
Novada Shopping Mall	**0**
Optimum Outlet	**4**
Palladium Shopping Mall	**5**
Tepe Nautilus Shopping Mall	**4**
Water Garden Istanbul	**4**

In this thesis, AHP and TOPSIS methods are presented to rank the proposed locations for the electric vehicle charging stations. A case study is illustrated; the results point out the best location with respect to three criteria. The decision criteria for the charging station site selection are detemined after literature review and weihgted by the expert. AHP method is used to calculate the criteria by using Super Decision 2.0.8 Programs which is a decision support software that implements the AHP and ANP. According to the AHP results the most important criteria is Car parking situation (0.558), then follows Accessibility (0.319), and Traffic convenience (0.121). The composite weight of Brandium Shopping Mall is 0.0998, Bulvar 216 is 0.0690, Caddebostan Cultural Center is 0.0270, Icerenkoy Carrefour is 0.1491, Kozzy Shopping Mall is 0.0301, Novada Shopping Mall is 0.0605, Optimum Outlet is 0.1530, Palladium Shopping Mall is 0.1175, Tepe Nautilus Shopping Mall is 0.0995 and Water Garden Istanbul is 0.1942. With the help of composite weight of alternatives with recpect to three criteria, TOPSIS method is applied to rak the alternatives. According to C_i^* results, the best location is Water Garden Istanbul which has the highest C_i^* value of 0.7016 and the worst location is Caddebostan Cultural Center which has the lowest C_i^* value.

The results of phase one is used as input for the mathematical method to determine the number of charging station to site for the alternatives sites. For this reason, a mathematical model is developed to maximize the user utility under budget and capacity constraints to obtain optimal number of charging station for each alternative point. LINGO 17.0 Solver optimization tool is used to solve the model and optimal number of charging stations to locate is found out as illustrated in Table 4.4.2. Caddebostan Cultural Center, Kozzy Shopping Mall and Novada Shopping Mall requires no charging stations to locate, however we need to locate 5 charging stations to Icerenkoy Carrefour and Palladium Shopping Mall. The composite weights that we used in mathematical model affects the number of charging station to locate.

5. CONCLUSION

In recent years, because of the soaring price of oil and the environmental issues, automakers have offered electric vehicles for sustainable transportation. Developed countries consider the importance of the EVs and thus the number of EVs on road increase year by year. Unlike these countries, the advancement of EVs in Turkey is moderate. 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. In this thesis, 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 Kadıköy and Ataşehir, two districts of Istanbul. We formed three main criteria from the literature review to compare these alternative locations with each other. AHP and TOPSIS methodologies are 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 we integrated AHP and TOPSIS methodologies 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.

In our study, we considered shopping malls and cultural centers because they are appropriate places to locate Level 2 charging stations. We ignored Level 1 and DC fast charging stations. These two types of charging stations may be considered for different places in further studies.

In our mathematical model, we only considered budget and capacity constraints. 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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APPENDICES

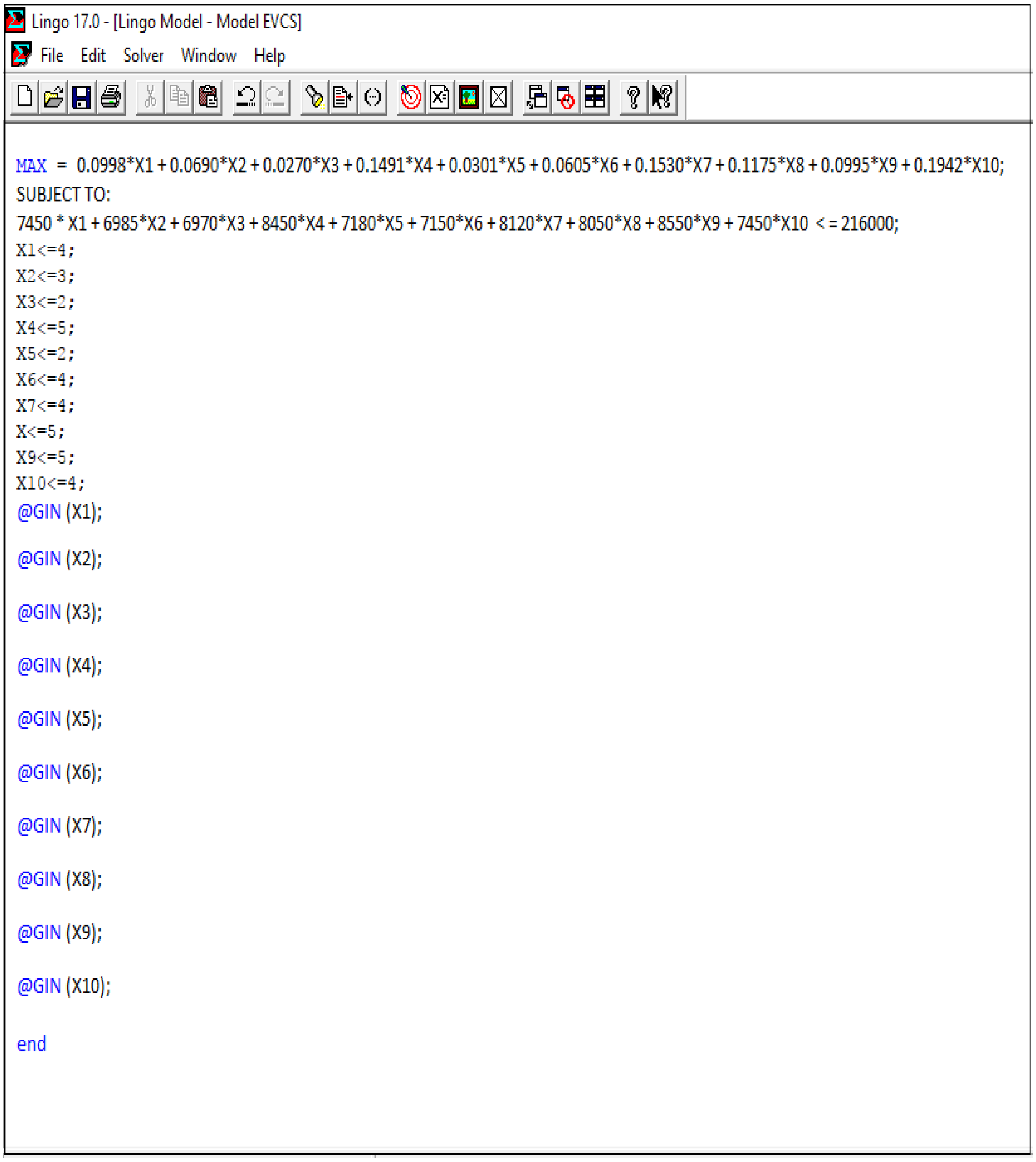
Appendix A. Closed Form of Mathematical Model in LINGO

Lingo 17.0 - [Lingo Model - Model EVCS]

File Edit Solver Window Help

```
MODEL:
! Locating Electric Vehicle Charging Stations in Istanbul;

SETS:
      STATION_I/1..10/: CAPACITY, COST, WEIGHT, X;

ENDSETS

DATA:
      CAPACITY WEIGHT  COST =
       4        0.0998   7450
       3        0.0690   6985
       2        0.0270   6970
       5        0.1491   8450
       2        0.0301   7180
       4        0.0605   7150
        4       0.1530   8120
        5       0.1175   8050
        5       0.0995   8550
        4       0.1942   7450;

      BUDGET=216000;

ENDDATA

! The objective;

MAX = @SUM(STATION_I(I): WEIGHT(I)* X(I));

! The budget constraint;

@SUM(STATION_I(I): COST(I)  * X(I))<=BUDGET;

!The capacity constraint;

@FOR(STATION_I(I):
@SUM(STATION_I(I): X(I))<= CAPACITY(I));

!Integer constraint;

@FOR(STATION_I(I):@GIN( X(I)));

END
```

Appendix B. Open Form of Mathematical Model in LINGO




```
MAX = 0.0998*X1 + 0.0690*X2 + 0.0270*X3 + 0.1491*X4 + 0.0301*X5 + 0.0605*X6 + 0.1530*X7 + 0.1175*X8 + 0.0995*X9 + 0.1942*X10;
SUBJECT TO:
7450 * X1 + 6985*X2 + 6970*X3 + 8450*X4 + 7180*X5 + 7150*X6 + 8120*X7 + 8050*X8 + 8550*X9 + 7450*X10 < = 216000;
X1<=4;
X2<=3;
X3<=2;
X4<=5;
X5<=2;
X6<=4;
X7<=4;
X<=5;
X9<=5;
X10<=4;
@GIN (X1);
@GIN (X2);
@GIN (X3);
@GIN (X4);
@GIN (X5);
@GIN (X6);
@GIN (X7);
@GIN (X8);
@GIN (X9);
@GIN (X10);
end
```

BIOGRAPHICAL SKETCH

Hatice KOCAMAN was born on August 8, 1990, in Erzincan. She graduated from Köy Hizmetleri Anatolian High School in 2008 then she started her bachelor education in Industrial Engineering in Okan University with a full scholarship. In 2013, she completed her education from İstanbul Okan University. Currently, she is working as research assistant at OkanUniversity and pursuing her master's degree ın Industrial Engineering under the supervision of Assoc. Prof. Dr. Müjde EROL GENEVOIS at the Institute of Science and Engineering.