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Optimizing the electric charge station network of EŞARJ

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Abstract

In this study, we adopt the classic capacitated p-median location model for the solution of a network design problem, in the domain of electric charge station network design, for a leading company in Turkey. Our model encompasses the location preferences of the company managers as preference scores incorporated into the objective function. Our model also incorporates the capacity concerns of the managers through constraints on maximum number of districts and maximum population that can be served from a location. The model optimally selects the new station locations and the visualization of model results provides additional insights.

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1. Introduction

Widespread use of plug-in electric vehicles can significantly reduce greenhouse gas emissions. Because plug-in electric vehicles do not emit greenhouse gases, they do not directly contribute to the emissions of these gases. Thus, global greenhouse gas emissions reduction goals can be achieved or at least approached through extensive adoption of plug-in electric vehicles. Due to environmental and economical motivations, plug-in electric vehicles are expected to become increasingly important in the upcoming decades[1].

As plug-in electric vehicles enter the market, a huge demand for charging stations is expected[2]. To this end, providing adequate charging station infrastructure becomes a necessity for the success of electric vehicle technology in the market. If sufficient charging infrastructure is provided, there will be a possible increase in public motivation for this technology through reducing the plug-in electric vehicle owners' current anxieties over the mileage range. Ease of access to the charging stations will affect plug-in electric vehicles adoption rates, petroleum demand and electricity consumption across the times of a day[2].

In this paper, we aim to apply a facility location model to decide on how to install a constrained number of charging stations for Eşarj[3], a leading electric vehicles charge system operator in Turkey.

2. Literature

Papers are available that consider various aspects of the electric charge station network design. Frade *et al.*[4] use a maximal covering location model and apply it to Lisbon, Portugal. They aim to maximize the plug-in electric vehicle demand served by the charging station infrastructure. Hanabusa and Horiguchi[5] develop and solve a model to minimize plug-in electric vehicle travel cost, assuming a minimum buffer distance between charging stations as a constraint. They use travel time of the plug-in electric vehicles and waiting time at the charging stations to develop a cost function for the travel cost. Chen *et al.*[2] use a mixed-integer optimization model to reduce costs as a function of walk distance between two districts.

3. Company

Eşarj Electrical Vehicle Charging Systems (http://esarj.com) was established in 2008, and is rapidly developing in this market since then. R&D operations of the company elevate it to a prominent position in the electrical charging network business. In 2010, Eşarj signed a partnership agreement with Efacec Engenharia e Sistemas, a Portuguese company that leads Europe with significant operations in 65 countries. In 2011, Eşarj made an agreement with Renault Turkey, and became a solution partner for Renault Electrical Vehicles (EVs). Eşarj is constantly improving the electricity infrastructure for Renault EVs of Renault dealers, while extending its charge station network through other means.

Eşarj has particular missions pinpointed to improve current infrastructure facilities in Turkey. First, Eşarj contributes to electrical charging infrastructure through legislations, management and engineering. Furthermore, installing an extensive supply network for electrical charging stations is a priority of the company. Eşarj also provides service for individual customers with home type charging stations. Additionally, the company works towards becoming the national network operator of charging stations by providing charging solutions and network management systems at every charging point.

Eşarj has specific primary missions: Improving service and product quality continually for customers is the highest priority of the company. The next priority is providing extensive options for products and solutions. Other visionary priorities include protecting natural environment and reducing carbon emissions by encouraging customers to use EVs, and contributing to the energy independence of Turkey in the electrical vehicle market and electrical energy.

The study that we present in this paper looks into the strategic facility location decision of Eşarj, following the principle agreement with the leading car-sharing company in Turkey, YoYo (http://driveyoyo.com). YoYo is the Turkish counterpart of Zipcar, and rents cars for short intervals, rather than for several days. The partnership guarantees benefits to both parties. A primary strategy of YoYo is to operate a fleet of electric vehicles, besides fuel-based vehicles. This will help in decreasing costs and enable YoYo to lead its industry as a leader of sustainability. Meanwhile, the agreement will allow Eşarj to use the established network of YoYo in shopping malls and erect vehicle charge stations in these locations, without having to convince each of the malls, or having to go through long negotiation cycles.

The strategic problem at hand is simple and classic: Which of the 32 potential new YoYo locations should Eşarj prioritize, besides its 4 existing non-Renault stations, for erecting charge stations?

Although the problem can be modeled as a pure p-median problem, some complicating constraints call for an alternative model, namely a variant of the capacitated p-median problem.

4. Model

P-median location model locates *p* charging stations in relation to a set of customers, such that the sum of the weighted distances between the customers and charging stations is minimized[6]. The *capacitated p-median location model* imposes a capacity constraint on the locations[7]. In our study, we adopted the classic capacitated p-median location model with additional constraints and the consideration of preference scores. The model is taken from Yaghini *et al.*[7], with the addition of constraint (constraint (4) in the model below).

The applied model is given and explained below. The modeling process begins with the identification of the sets (the districts and potential locations) and the parameters:

Sets:

$\mathcal{I}$: set of districts (demand points, customers) to be served

$\mathcal{J}$: set of potential locations where electric charge stations can be erected

Parameters:

D_i: demand at district i (population of district i)

$d_{i,j}$: distance between district i and candidate location j

p_j: preference score for candidate location j; higher values denote higher preference; $p_j \in \{1 \cdots 5\}$

P: number of charging stations to locate

MaxDistricts: maximum number of districts to be served by a location

MaxPop: maximum population to be served by a location

The decision variables tell where the stations are located and which districts each location serves:

Decision Variables:

$$y_j = \begin{cases} 1 \; if \; we \; locate \; at \; candidate \; location \; j \\ 0 \end{cases}$$

$$x_{i,j} = \begin{cases} 1 \; if \; customer \; i \; is \; served \; by \; location \; j \\ 0 \end{cases}$$

The full model, with all the constraints included and the preference scores embedded, is as given below:

Mathematical Model:

$$min \sum_i \sum_j D_i * d_{i,j} * \frac{1}{p_j} * x_{i,j} \tag{1}$$

subject to

$$\sum_j x_{i,j} = 1 \qquad \forall \, i \tag{2}$$

$$\sum_j y_j = P \tag{3}$$

$$\sum_i x_{i,j} \leq MaxDistricts \qquad \forall \, j \tag{4}$$

$$\sum_i D_i * x_{i,j} \leq MaxPop \qquad \forall \, j \tag{5}$$

$$y_j = 1 \qquad j = 1 \cdots 4 \tag{6}$$

$$x_{i,j} \leq \; y_j \qquad \forall \, i,j \tag{7}$$

$$x_{i,j} = 0,1 \qquad \forall \, i,j \tag{8}$$

$$y_j = 0,1 \qquad \forall\, j \tag{9}$$

The objective function (1) is the summary of a set of cost components over i and j. Each cost component is the multiplication of the demand of the district with the distance traveled to the location to which it is assigned, divided by the preference score for that location. The objective function penalizes larger demands traveled over longer distances, but rewards higher values of the preference scores (provided by Eşarj management). Although there can be several ways of reflecting the preference scores, this simplest form has been selected for easy communication with Eşarj and Yoyo.

The constraints are: (2) Each district is assigned to a single location. (3) A maximum of P locations are to be located. (4) A limit of *MaxDistricts* is placed on the number of districts that a location can serve. (5) A limit of *MaxPop* is placed on the population that a location can serve. Eşarj was particularly interested in this constraint, because they would prefer a balanced distribution of traffic to different stations and because they would prefer to install stations with similar capacities to different locations. (6) The first four locations have existing Eşarj stations, already decided and located. (7) Linking constraint between the binary variables. (8, 9) Binary variables.

5. Data

Data for the demand points (districts) was obtained for each district in Istanbul, Turkey through a commercial database. Then (age 18+ only) population of each district was obtained from the results of the 2011 general election through another commercial database. Additionally, coordinates for the potential charging stations was obtained from Eşarj (which obtained the data from Google Maps) as (*lat*, *long*) pairs where *lat* is the latitude of the potential location and *long* is the longitude of this location.

First, all possible points were enumerated with unique IDs to ease the processing of data. Besides IDs, coordinates of possible locations were also recorded in the spreadsheet to calculate the distances among the charging points. Then the distance matrix was recorded in a new sheet.

During data cleaning, all the districts and potential locations have been plotted in a scatter plot to identify outliers. Fig. 1 displays the initial data as plotted. Because extreme outlier points (on the outskirts of Istanbul) may distort the optimal solution substantially, they were removed after communication with Eşarj management. The removed outlier points are shown in Fig. 2. As can be observed in Figure 2, the outliers are very far from the clusters of districts, and could result in stations being located near them, disrupting the service to central districts. It should also be noted that these outlier districts are also typically smaller villages of Istanbul, where electric cars have not yet penetrated. Thus it is appropriate to remove them from the dataset.

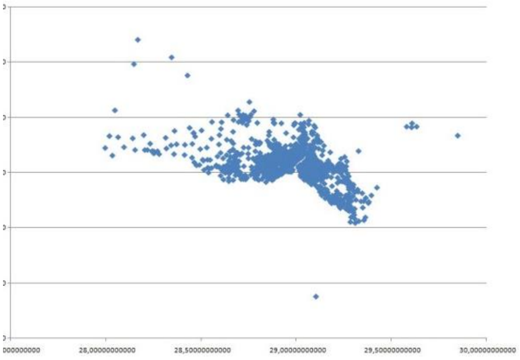


Fig. 1. Scatter plot of geographical locations of districts that have been removed from the data

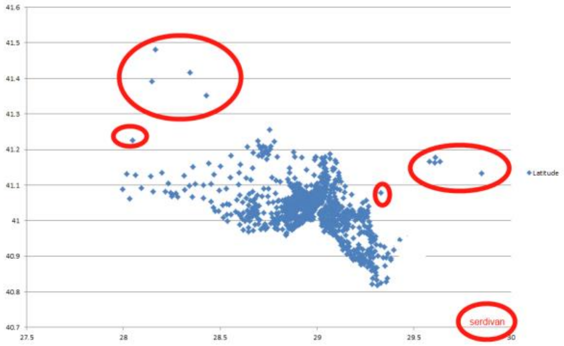
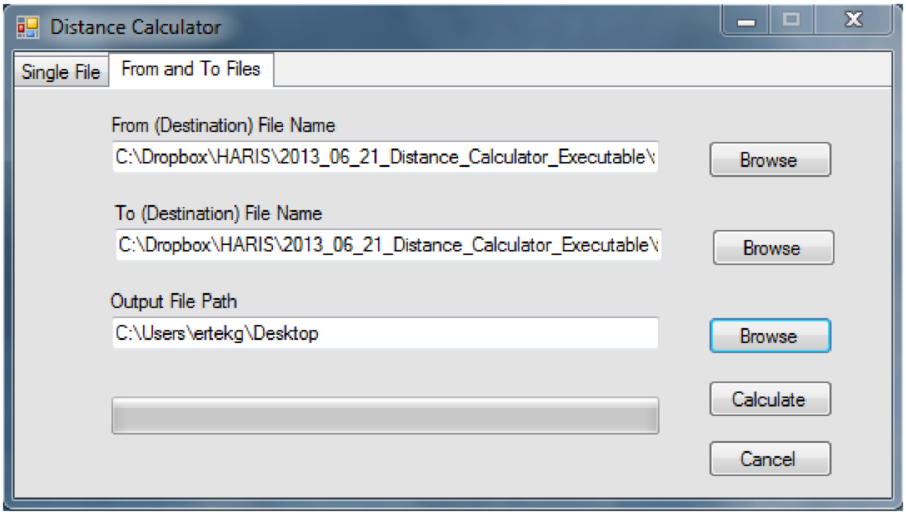


Fig. 2. Outlier districts

Finally, the distance matrix was created from obtained data using custom-developed software (Fig. 3). The software acquires the road distances and puts them into the distance matrix by automatically querying them from Microsoft Bing Maps. It was crucial for our problem that the road distances be used instead of the Euclidean distances, especially because of the Bosporus strait that flows through the middle of Istanbul. Any model built on Euclidean distances for both the European and Asian sides of Istanbul at the same time would be highly inaccurate because of the existence of the strait that flows through the two sides. After its construction, the distance matrix (from the districts to the potential locations) was used in the OPL optimization model by importing from the data file. After the data was completed and placed in the model, the model was run using IBM ILOG OPL Development Studio 6.3 modeling software, with CPLEX as the solver engine.



From (Destination) File Name
C:\Dropbox\HARIS\2013_06_21_Distance_Calculator_Executable\

To (Destination) File Name
C:\Dropbox\HARIS\2013_06_21_Distance_Calculator_Executable\

Output File Path
C:\Users\ertekg\Desktop

Fig. 3. Custom-developed Distance Calculator software

6. Analysis and Results

Eventually, Eşarj plans to establish stations to all the shopping malls where Yoyo is located. However, the current problem is to select the most appropriate 15 locations. The sensitivity of the objective function with respect to different values of *MaxDistricts* was investigated, as in Figure 4. The objective function value itself does not have a particular economic meaning, but rather is a measure of the incurred cost and the subjective preferences of Eşarj managers regarding the locations. Finally, the model was run for P=15, *MaxDistricts*=90, and *MaxPop*=100,000.

Figure 5 visualizes the optimal solution. The visualization shows the selected (filled circles) and unselected locations (cross out signs) and districts (small hollow circles). The visualization shows that although some selected locations are serving populated regions or areas with many districts, many districts in the outskirts of the city are far from their nearest station. Because these outskirt districts are not densely populated, the solution seems a logical one. The solution, and other results, will be further discussed with Eşarj managers to devise the most appropriate selections based on Eşarj's business model and strategic priorities.

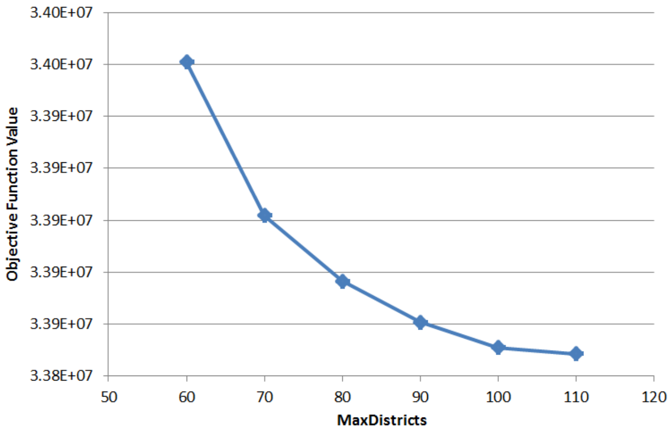


Fig. 4. Objective function value as a function of *MaxDistricts*, for the model.

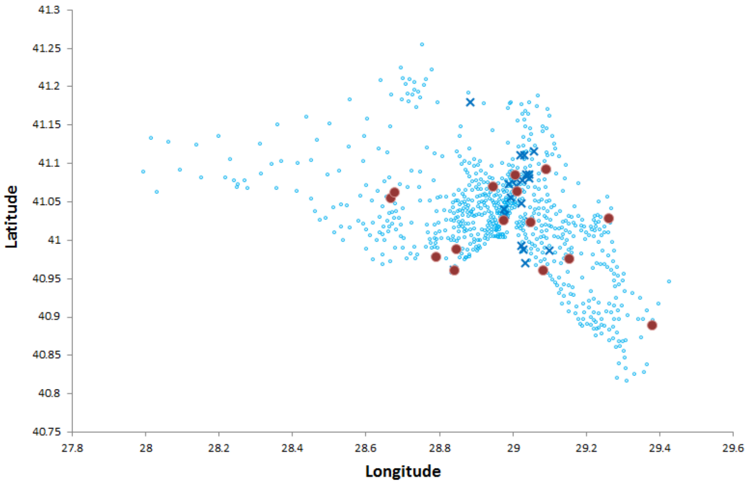


Fig. 5. Model solution, for scenario-model combination A4. Small circles show the districts, cross out signs (x) show unused locations (y_j=0), and filled circles show selected locations (y_j=1).

7. Conclusions and Future Work

P-median location model locates *p* charging stations in relation to a set of customers, such that the sum of weighted distances between the customers and charging stations is minimized. In this study, we adopted the capacitated p-median location model with an additional constraint and the consideration of preference scores, for the solution of a network design problem. The study presents the application of an optimization model for the domain of electric charge station network design, although similar models have been used in other domains. Our model encompasses the location preferences of the Eşarj managers as preference scores incorporated into the objective function. Our model also incorporates the capacity concerns of the Eşarj managers through constraints on maximum number of districts and maximum population that can be served from a location. The visualization of model results provide additional insights, although developing and solving various models enables an ad hoc ranking for the prioritization of the locations to be selected.

Considering the growing importance of sustainability around the globe, our study is expected to be a benchmark for similar studies by other electric vehicle charging companies throughout the world.

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