Optimization of Network Design for Charging Station Placement : A Case Study

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Abstract

The use of electric vehicles (EV) is quite a lot. With so many EVs scattered, it is necessary to plan the placement of a filling station that takes into account all the components of tractive effort, regenerative braking, and parasitic power users. Actual driving distance and altitude data from Google Maps are used as data for placement of filling stations and can therefore far more accurately predict the range that can be achieved from a given EV than a typical Euclidean distance model. In addition, the optimization model for filling station placement considers the number of affordable households in the filling station procurement plan. One problem in this study is the importance of meeting the increasing demand for EV fuels. Considerations for adjusting existing EV levels. The proposed optimization technique is applied to the transportation network, and in the case study in the Solo area, where the focus is to reach the maximum range with the minimum number of filling station distances. The results are promising and show that flexibility, smart route selection, and numerical efficiency of the proposed design techniques, can choose strategic locations to fill stations from thousands of possible locations without numerical difficulties.

Keywords
Optimization, Charging station, Placement

1. Introduction

With the development of EV, the planning of electric vehicle charging stations (EV) has become an important concern of distribution network planning. In this study, the load density method was introduced to determine the optimal capacity of the EV filling station in the area to be planned, and there are things to be considered to calculate the charging station cost coefficient. Then the intent and purpose of the proposed SCND model that will be proposed is the procurement of a charging station that can cover requests with a minimum distance and consider the costs to be used. The driver distribution pattern is widely used to optimize the placement of the charger station. One solution developed is to know the behavior of EV users to predict when and where a vehicle will be parked (Chen et al, 2013). Weighted Voronoi diagram was used for the placement, size, and division of the filling station service area. Placement of the charging station can be analyzed with several points of view, which may include EV energy deficits, available power infrastructure, popular parking locations and residence time, minimizing overall energy, minimizing congestion, etc. This research was conducted to obtain a solution to the problem of placing an optimal filling station from the point of view of reaching most customers or households. On the other hand, this issue has also become one of the main topics for cities, electricity companies, and federal agencies such as environmental protection agencies and the transportation department. This concept was developed easily which can be used in conjunction with the other criteria mentioned above, the placement method is based on predetermined criteria to optimize the number of charging station placements. Therefore, this criterion will be used in the form of location restrictions. In this paper, the optimization problem for the charging station placement is investigated based on EV energy consumption, costs used, and coverage of EV users.

Maximum cover location model and applied it to Lisbon, Portugal (Frade et al, 2011). They aim to maximize the demand for plug-in electric vehicles that are served by infrastructure charging stations. Model develop and solved to minimize plug-in travel costs for electric vehicles, assuming a minimum buffer distance between charging stations as an obstacle. They use the electric vehicle plug-in travel time and waiting time at the charging station to develop a cost function for travel expenses (Hanabusa et al, 2011). Mixed integer optimization model used to reduce costs as a function of the walking distance between the two districts.

The research method looks at the geographical factors and radius of EV station charging service, for the purpose of constructing the EV station charging model considering location and capacity (Zhipeng et al, 2012) . Centralized charging, integrated distribution' operating mode is introduced, with a centralized charging station model built to determine capacity (Ciwei et al, 2012). Convenience and economy are both considered to optimize the charging station layout and modeling of radial distribution system planning (Aihu et al, 2011).

In the case of decentralized network access modes, an autonomous distributive strategy for frequency modulation is proposed, this method considers EV requests and modulates frequencies according to frequency deviations (Oya et al, 2011). Adaptive frequency drop method to meet frequency requests (Liu et al, 2013). Include the problem of managers' capacity through limiting the maximum number of districts and maximum population that can be served from a location (Gavranovića et al, 2014). Load density method to determine the optimal capacity of the EV filling station in the area to be planned, and the difference between 1 and the weight coefficient obtained by the analytic hierarchy process (AHP) was used to calculate the charging station cost coefficient (Lin et al, 2014).

The optimal solution is applied to complete the proposed model. Proposed a stochastic flow capture model optimizing the location of fast filling stations, addressing the uncertainty of BEV flow (Wu and Sioshansi, 2017). Propose a model that simultaneously handles the problem of where to find a charging station and how many chargers should be set at each charging station to minimize the total cost (Zhu et al, 2016).

2. Methodology

The problem in this research is to focus on planning the placement of filling stations to meet customer needs. The consideration that will determine the results of the optimization model that will be built is the minimum distance that will be used to cover the demand for power that is spread in the city of Solo. Supply chain planning is needed because the design to be implemented must consider the location, consumer distribution, and also the costs that must be incurred. This will create optimal results for the stakeholders involved, a number of things considered will help the model to achieve optimal results.

From this statement, it has been explained that in this study there were several supply chain activities that took place. This model has designed the filling station construction site by considering the distance. And with that, the next activity is to plan the development and capacity of each filling station to meet consumer demand.

- Government: provides direction and restrictions on rules for the use and construction of filling stations in the city.
- Manufacturer: build a charging station according to existing standards.
- Engineer: checks the optimal location in carrying out the construction of the filling station and considers the costs incurred.
- Consumers: as objects as one of the things that determines the location of filling stations that are built. Because facilities are built to meet consumer needs.

The optimal filling station strategy and placement is one of the important studies for successful development and this issue has become a major concern in research. Some literature describes several methods used to allocate optimal gas stations in the transportation network. The proposed method can be roughly divided into flow capture models (Kuby et al, 2005; Upchurch et al, 2009; Wang et al, 2013; He et al, 2018), cover models (Wang et al, 2018; Wang et al, 2018), vehicle movement simulation models (Frade et al, 2011; Dong et al, 2014), agent-based models (Sweda et al, 2011), and balance models (He et al, 2013; He et al, 2014; He et al, 2015). This study focuses on creating models to identify the location of optimal filling stations for EV on the road transport network. location, so that every EV in the transportation network can reach the charging station before the power used in electric vehicles is used up. The route identified in the Solo area is one of the things considered in developing the model. The average number of vehicles in operation, the location of public facilities, and also the costs to be incurred by the owner of an electric vehicle. This research will discuss the development of a model with the following scheme: displaying data from the city of Solo. Model development, analysis and interpretation of optimization results, and drawing conclusions from the results of discussion of the models that have been built. And the last one concludes this paper and discusses the direction of further research.

Figure 1 explains the flow of making a filling station that will be a power source on electric vehicles. Material movement in this case is the construction of facilities at each predetermined point. This includes the flow of raw material supply chains and the technology that will be used. Then for the information flow that occurs illustrates information about existing EV users, the capacity of each charging station that can accommodate EV user requests in the area. For purchases or sales, EV user development will have an impact on the number of filling stations that need to be held. This can be seen from the increasing demand.

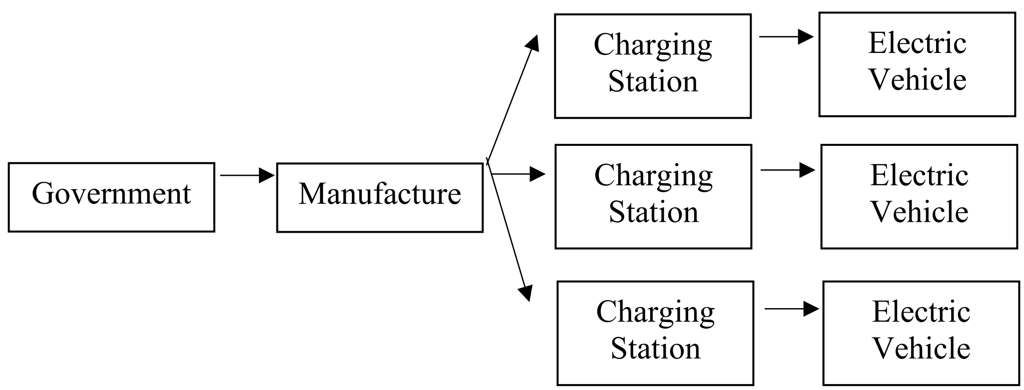

Figure 1. Supply Chain Management of Charging Station

There are several stages carried out in this study. Data collection for the Soloraya region as a research location includes distance and crowded places, data on consumer distribution, data on filling station capacity to be built, cost data on maintenance and depreciation from EV, transportation cost data and other supporting data obtained from journals and literature reviews.

Literature studies are examined from various research sources that have a correlation with research on optimizing the placement of electric stations charging stations, then observations are carried out for 2 weeks to one month to determine the environmental conditions in the transportation lane, research conducted in the Soloraya area which includes the distribution of EV users, then modeling distance optimization to get the optimal filling station by considering the costs involved. After all this is done, the model is validated with the existing conditions. If the model is able to approach the system and the model is already sensitive then an analysis and interpretation of the results will be carried out to illustrate the results of the research that has been done.

Data needed includes: location data, distance between locations in Soloraya. Distribution of consumer data at Soloraya. Some data obtained from the official system of the Solo city government. Bearing this in mind, optimal results are obtained from construction sites and the distribution of filling stations. And with consideration of the optimal costs so that the process of procuring existing facilities is considered quite useful and beneficial for various parties. From several references, the model obtained will be modified into a model to achieve the objectives of the research conducted.

3. Result and Discussion

There is a reference model used in this study, this model aims to find the minimum number of charging stations, their location allows for coverage of the number of EV users which makes it easiest in the transportation network to build a charging station. This model is quite appropriate to be used as a reference because the model also discusses the coverage that will be used by stakeholders to determine the location of the charging station construction in order to cover requests from various regions.

Indices

i	index nodes of candidate sites for charging stations in the network, i ∈ **I**, **I** is the node set
A	set of links
R	set of routes, j ∈ R
d	The number of nodes in the network

Parameters

j	the number of district = i
i	number of charging station

Constraints

C_{ij} = 1 if node i ∈ **I** is contained in the route j, and δ_{ij} = 0 otherwise
Node i ∈ **I** is built if at least one charging station is placed. More formally,
a nodes i ∈ **I** is built if $\sum_{\mathbf{i \in N}} \boldsymbol{\delta}_{ij} x \geq 1$
m=i

Objective Function

$z = \min \{\sum_{i \in I} \sum_{j \in J} dist_{ij} d_j Y_{ij}, \forall \boldsymbol{j} \in \boldsymbol{R}, \boldsymbol{x} \in (\mathbf{0}, \mathbf{1})^d\}$
(1)

Subject to

$\sum_{i \in I} Y_{ij} = 1; \forall j \in R$ (2)

$\sum_{i \in I} X_I = P$ (3)

$Y_{ij} = X ; \forall j \in R ; \forall i \in I$
(4)

$Y_{ij} \in \{0,1\} ; \forall j \in R ; \forall i \in I$ (5)

$X_i \in \{0,1\} ; \forall j \in R$ (6)

Route Node Coverage (RNC) considers in current paper is to find minimum number of charging station, their location allows for coverage of the number of EV users that makes it easiest in the transportation network to build a Charging station. The proposed method to solve our RNC problem based on integer programming, and the outline of the method describe as the following basic steps:

- Initialization: Set R = ∅. Fix x_i = 1 if a charging station is already allocated at node i ∈ N, and fix an upper route length bound c
- Given a reference set $R_k \subset R$, solve the sub problem

$$z = \min \{\sum_{i \in N} x_i : \sum_{i \in N} \delta_{ij} x_i \geq 1, \forall j \in R, x \in (0,1)^d\} \quad (7)$$

- Define the entering index R by nodes i on route j with c(i) ≤ c. Stop, if a new Re cannot be found according to some termination criteria. 3.
- Define the new reference set by R_k+1 = (R_k ∪ {R}) and go to step 1.

Table 1. Solo population data

Age	**Male**	**Female**	**Sum**
0-4	17 693	16 881	34 574
5-9	18 251	17 346	35 597
10-14	17 592	16 999	34 591
15-19	22 334	24 467	46 801
20-24	27 043	27 017	54 060
25-29	20 953	19 774	40 727
30-34	18 364	18 602	36 966
35-39	17 710	19 051	36 761
40-44	17 594	18 925	36 519
45-49	16 702	19 192	35 894
50-54	16 384	18 810	35 194
55-59	14 806	16 492	31 298
60-64	10 600	11 111	21 711
65+	15 746	21 448	37 194
Sum	251 772	266 115	517 887

(Source: BPS Solo)

From the table above, it illustrates that the total population in the city of Solo is 517,887 people. Active users for motorbikes are aged 17 to 59 years, this shows that 354,220 people are the target market for electric motorcycles. However, because the interest of customers in owning an electric motorcycle is still not high, the demand in this model is still brought by 5000 users. This user will be spread based on the level of activity density in an area. This will later also affect the amount of demand from each region in the city of Solo.

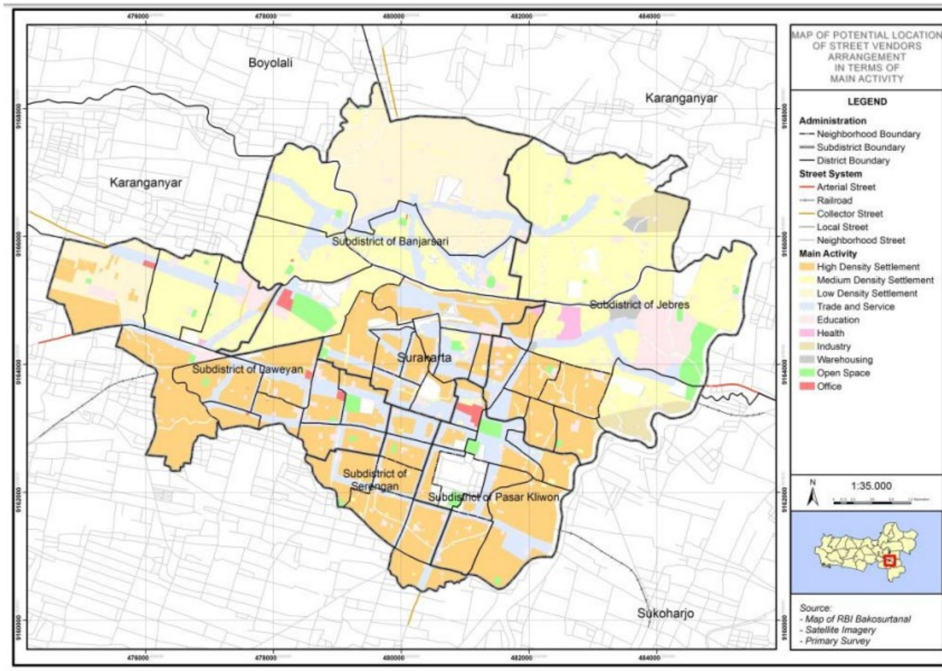

Fig 1. Level of activity in Solo

The picture explains the level of crowded environment in the city of Surakarta. this shows active activity so that it is suitable to be used as a place to build a charging station because it is the center of activity in a city. With the existing density, the region is divided into sections according to the existing density level. Areas with this activity need more charging stations than usual, because the capacity of use in this region is greater than other regions. From the road data obtained by the researchers, the road limitation for constructing a charging station is 50 km. This is due to the electric motorcycle being able to cover a distance of 50 km in one time charging..

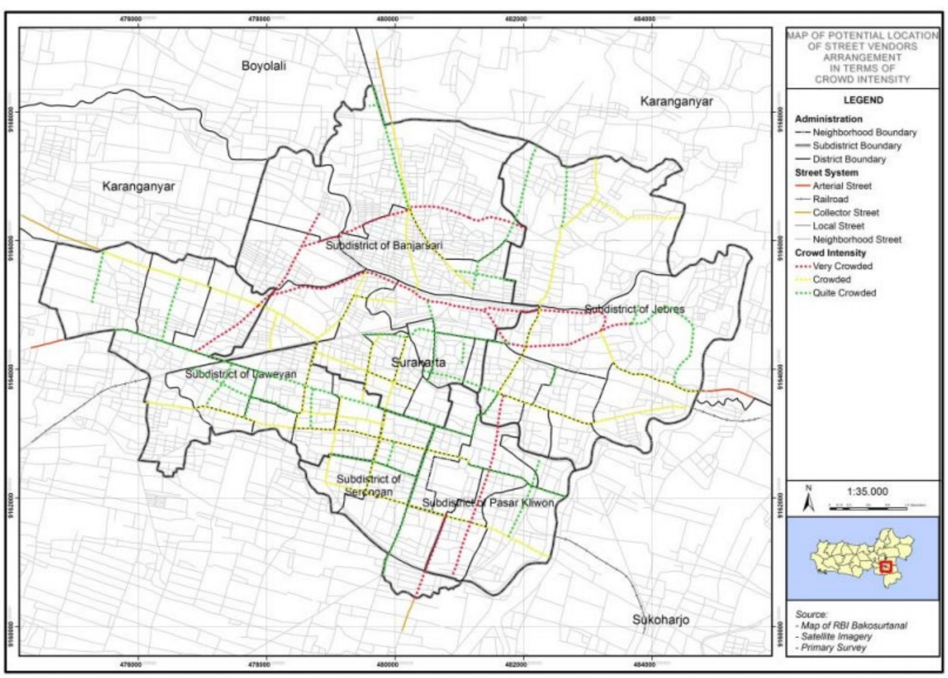

Fig 2. Intensity of highway noise

With a map of the distribution of crowded intensities that exist in a city, then the right route is obtained to construct the charging station. it also covers a number of people living in the area. With different demand for each region, and distance from each area is minimized.

Numerical Example

Table 2. Demand from each area

Set of Area	Demand-j
Area 1	287
Area 2	572
Area 3	345
Area 4	350
Area 5	201
Area 6	333
Area 7	306
Area 8	233
Area 9	341

From the distance obtained from the city of Solo, there are 5 facilities that are at least built to meet the needs of customers in charging batteries. With this demand, there is a relationship with the distance between areas. With the distance between these areas, it can be determined where the construction of the right charging station that can cover all existing demand.

Table 3. Distance data between areas

Distance Matrix	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
Area 1	0	720	790	297	283	296	461	769	996
Area 2	720	0	884	555	722	461	685	245	1099
Area 3	790	884	0	976	614	667	371	645	219
Area 4	297	555	976	0	531	359	602	715	1217
Area 5	283	722	614	531	0	263	286	629	721
Area 6	296	461	667	359	263	0	288	479	907
Area 7	461	685	371	602	286	288	0	448	589
Area 8	769	245	645	715	629	479	448	0	867
rea 9	996	1099	219	1217	721	907	589	867	0

Table 4. Optimal location of charging station construction

Y- i,j	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
Area 1	0	0	0	0	0	0	0	0	0
Area 2	0	1	0	0	0	0	0	1	0
Area 3	0	0	1	0	0	0	0	0	1
Area 4	0	0	0	1	0	0	0	0	0
Area 5	0	0	0	0	0	0	0	0	0
Area 6	1	0	0	0	1	1	0	0	0
Area 7	0	0	0	0	0	0	1	0	0
Area 8	0	0	0	0	0	0	0	0	0
Area 9	0	0	0	0	0	0	0	0	0
Must Be Supplied	1	1	1	1	1	1	1	1	1

With this data, a charging station construction site can be found that can cover the needs of consumers. There are 5 charging stations to be built, charging station area 6 will cover area 1, area 5, area 6, charging station area 2 will cover area 2 and 8, area 3 will cover area 3 and 9, area 4 and 7 will cover the area each. With this, the average amount of distance can be minimized.

4. Conclusion

From this study, we got a solution that the amount of charging that is spread in several locations that have reached the demand of the number of customers. It also considers the distance from each charging station that is built. With this optimal solution, it will be easier for customers to charge from one place to another. Costs incurred in the construction have also been reviewed, so the costs incurred are minimal costs for the planned construction of a charging station in the city of Solo.

Future studies might consider demographic conditions, traffic congestion, and also the average speed of electric vehicle drivers. This is a limitation that is quite influential in optimizing the placement of charging stations. With this adjustment, the assessment system in finding optimal solutions also makes it easier for EV users. The data needed should also be more complete and accurate.

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