Optimizing Location of Public Electric Vehicle Charging Station for Electric Motorcycles: A Case Study of Surakarta City

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Abstract

In a few years, electric vehicles will transition to vehicles that are massively used in transportation activities in order to reduce carbon footprint. The Indonesian government is committed to achieving the 'Net-Zero Emission' target by 2060. In its implementation, the existence of electric motor charging infrastructure such as charging stations is one of the critical factors in the electric vehicle adoption program. Consumers will feel anxious if their vehicle runs out of battery in the middle of their journey before reaching their destination. Therefore, this study focuses on determining the location of charging stations in Surakarta City, Central Java, Indonesia which is targeted to be an effective strategy in providing a large initiation impact on emission reduction in Central Java Province. This research takes into account the placement of locations that are suitable for electric motor users so that the utility of charging stations is optimal and able to serve electric motor users in Surakarta City with the minimum travel cost. The method used is it applies optimization model: a mixed integer linear programming (MILP) model to find the optimal locations for new charging stations that can maximize the coverage of the demand. This study uses user data, travel routes, and candidate charging station location points as data initiation for optimization models. The optimization is run to determine the most optimal solution for location of charging stations that consider electric motor users' travel costs so that the demands can be met well.

Keywords
Electric Motorcycle; Charging Stations; Location; Mixed Integer Linear Programming.

1. Introduction

Transportation plays a vital role in daily life, especially in countries like Indonesia, where motorcycles are one of the most dominant modes of transportation. The Central Statistics Agency (2021) records that the number of operating motorcycles in Indonesia has reached 120 million units. This rapid growth will have negative impacts if left unaddressed without decisive intervention. Emissions produced by motorcycles contribute to air quality degradation, as well as increased greenhouse gas emissions contributing to global climate change. Therefore, innovation in electrifying motorcycles is necessary to prevent these issues, in line with the Indonesian government's commitment to achieve 'Net-Zero Emission' by 2060.

In the context of electric motorcycle downstreaming, the transition of market share cannot be optimally executed without fulfilling the basic needs of electric motorcycle users. One such need is the availability of recharging facilities, such as Public Electric Vehicle Charging Stations (PEVCS). The presence of electric motorcycle charging infrastructure plays a crucial role in the electric motorcycle adoption program. As much as 83% of consumers prefer fossil-fuel motorcycles over electric motorcycles due to concerns about running out of battery during their journey (Haidar 2020). User access to PEVCS is also closely related to travel costs. The more strategic the optimization and centralized planning of PEVCS locations, the more drastically travel costs for electric motorcycle users and the initial costs required to meet charging demand will be reduced (Z. Lin et al. 2008). Consumers will opt for electric motorcycles if they can save on travel costs compared to conventional motorcycles (Ling Z et al. 2021).

In general, the apprehension about the insufficiency of electric motorcycle power to complete a journey and reach the destination is referred to as 'range anxiety' (Istiqomah 2022). This concern arises due to the limited availability of adequate PEVCS facilities. Personal electric motorcycle users with a maximum capacity of 6.5 kW to 12 kW can cover an average distance of 19 km for a one-way journey (Asian Development Bank 2022). Thus, the installation locations of PEVCS are needed on departure or destination routes to alleviate range anxiety and reduce travel costs incurred by electric motorcycle users to reach PEVCS.

Several previous studies have developed optimization models for placing PEVCS that focus on population activity density. A similar case study in Surakarta City by Istiqomah (2022) was conducted using mathematical optimization models to maximize electric motorcycle user demand coverage, resulting in 7 potential hierarchical areas for PEVCS construction. This study focuses on determining optimal PEVCS locations to minimize travel costs by considering the Euclidean distance metric between candidate PEVCS locations and demand charging locations, utilizing population density data for each sub-district in Surakarta City, several points of interest such as gas stations and shopping centers, as well as user travel routes.

1.1 Objectives

The objectives of this research, based on the formulated problem statement, are twofold. Firstly, the study aims to develop an optimization model for determining the optimal locations of Public Electric Vehicle Charging Stations (PEVCS) in Surakarta City. This model takes into account both the charging demand of electric motorcycles and potential candidate locations for the PEVCS. Secondly, the research intends to identify the most suitable SPKLU (Stasiun Pengisian Kendaraan Listrik Umum) locations within Surakarta City. These optimal locations are chosen to efficiently accommodate charging demands while minimizing travel costs incurred by electric motorcycle users. By achieving these objectives, the study contributes to the development of an effective and well-placed charging infrastructure for electric motorcycles, thus encouraging wider adoption of environmentally friendly transportation alternatives.

2. Literature Review

PEVCS is a facility for charging battery-based electric motor vehicles. The potential charging systems used for electric motorcycles can be classified as home charging, which is charging at home, destination charging, which can be referred to as PEVCS, and battery swapping, which can be referred to as BEVCS (Asian Development Bank 2022). The Indonesian government has opened the doors for investment and cooperative infrastructure development of PEVCS to expand the market share of electric motorcycles on a larger scale. As of February 2023, a total of 346 PEVCS units are available, distributed across 295 locations in Indonesia (Ministry of Energy and Mineral Resources 2023).

The determination of facility locations involves a decision-making process for placing facilities in certain areas, considering factors such as demand, infrastructure, costs, and population (Nur 2019). Location-related issues encompass the optimal placement to serve the needs of electric motorcycle users with the minimum transportation cost from the facility to users, and vice versa (Suomalainen 2006).

Mixed-Integer Linear Programming (MILP) is one linear programming technique used for allocating limited resources among competing activities (Al kautsar 2023). This method utilizes mathematical optimization involving the search for the best values of variables that satisfy linear constraints and linear objective functions (Kantor et al. 2020). The MILP optimization technique involves both integer and real-valued variables, along with linear objective functions and constraints (Lindholm et al. 2020). MILP optimization algorithms can be applied to select a subset of charging stations to be installed by minimizing the travel costs of electric vehicle drivers from the charging station to their destinations and penalties for unmet charging demands (Bodenschatz et al. 2020).

3. Methods

The corresponding research flow is visualized in Figure 1.

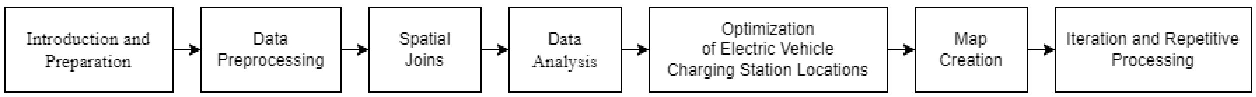

Figure **1.** Workflow of the research.

Step 1, Introduction and Preparation. In this phase, the initial steps involve importing essential libraries such as pandas, geopandas, and matplotlib, alongside others deemed necessary for the subsequent analysis. Moreover, the groundwork is laid for the geospatial analysis by assembling relevant datasets, including data pertaining to the locations of electric vehicle charging stations and census data. This preliminary stage forms the foundation for the subsequent data processing and analysis.

Step 2, Data Preprocessing. Data preprocessing is a crucial step aimed at refining the gathered information for analysis. Tasks within this phase encompass a variety of operations, ranging from merging disparate datasets to harmonizing coordinate formats. This stage also involves the combination of geospatial data sources, as well as the computation of essential statistical measures that will serve as building blocks for the subsequent analyses.

Step 3, Spatial Joins. Spatial joins involve the integration of geospatial datasets through the application of the `sjoin` method provided by Geopandas. This method facilitates the combination of data from different spatial layers based on their spatial relationships. In this specific context, the primary objective of spatial joins is to quantify the number of charging station points residing within distinct geographic polygons. This process aids in establishing a spatial context for the distribution of charging infrastructure.

Step 4, Data Analysis. The data analysis phase involves deriving valuable insights and parameters from the processed and joined datasets. Statistical computations take place to ascertain fundamental characteristics, including the count of charging points within individual polygons and the evaluation of charging station capacities. These statistics are integral to the subsequent decision-making processes, contributing to the identification of optimal charging station locations.

Step 5, Optimization of Electric Vehicle Charging Station Locations. Utilizing the principles of linear optimization, this phase employs mathematical techniques to identify the most suitable locations for electric vehicle charging stations. This determination takes into account both the anticipated demand for charging services and the associated costs. The iterative nature of this optimization allows for the consideration of varying demand ratios, ultimately yielding a set of ideal charging station locations corresponding to different levels of demand. The optimization method employed in this research utilizes Mixed Integer Linear Programming (MILP). MILP is employed to address the problem of determining PEVCS locations with an objective function and linear constraints outlined in the subsequent section. Based on the designed optimization model, the mathematical model utilized in the research is as follows:

$$Min \sum_{i}^{n} \sum_{j}^{m} c_{ij} x_{ij} + \sum_{j=1}^{m} f_j y_j$$

Which is subject to:

$$y_j \in \{ 0 , 1 \}$$

$$x_{ij} \leq d_i y_j, \qquad i = 1, 2, 3, \dots, n$$

$$\sum_{i=1}^{n} x_{ij} \leq My_J, \qquad j = 1, 2, 3, \ldots, m$$

$$x_{ij} \geq 0$$

The explanation for each notation is as follows:

i : index of demand location,

j : index of PEVCS loaction,

c_{ij} : total travel cost for electric motorcycle users from location i to PEVCS location j,

x_{ij} : charging demand of electric motorcycle users at location i served by PEVCS at location j,

f_j : fixed cost of installing PEVCS at location j,

y_j : {0 indicates not building PEVCS at location j, 1 indicates building PEVCS at location j},

d_i : total charging demand at location i,

M : capacity of electric motorcycle service at PEVCS,

m : number of PEVCS built at location j,

n : number of charging demands at locations

Step 6, Map Creation. To enhance the visual representation of the proposed electric vehicle charging station locations, interactive maps are generated using libraries like Folium. These maps effectively convey the spatial distribution of the selected charging points, aiding stakeholders in comprehending the optimized placements. By visualizing the results, decision-makers can better assess the practical implications of the proposed solutions.

Step 7, Iteration and Repetitive Processing. Recognizing the dynamic nature of electric vehicle charging infrastructure planning, this phase involves the repetitive execution of the optimization and mapping processes. The iteration is carried out for a range of demand ratio scenarios, catering to varying levels of charging requirements. This iterative approach ensures a comprehensive evaluation of charging station placements across a spectrum of potential usage scenarios.

4. Data Collection

Several data have been collected for the execution of this research, including travel data of electric motorcycle users in Surakarta City's neighborhoods. This data was obtained through direct interviews and online questionnaire submissions by respondents. It is utilized to map the journeys of electric motorcycle users in Surakarta City, as these journeys significantly influence the determination of PEVCS locations. The number of journeys serves as input for the demand charging generation model, which is then measured by the distance between the centroid point of each neighborhood's travel and the nearest candidate PEVCS. Optimal PEVCS locations are established at points with the least distance and the highest demand coverage.

Population density data per neighborhood in Surakarta City was obtained from the census archives conducted by the Surakarta City Statistics Bureau in 2021. Surakarta comprises approximately 50 neighborhoods. This data represents the number of residents per neighborhood divided by the area (km^2) of each neighborhood. It constitutes one of the input variables in the optimization process to map and calculate the charging demand weight for each neighborhood in Surakarta City. The denser the population of a neighborhood, the greater the weight of its charging demand, making it a priority for PEVCS placement. The map depicting the population density of Surakarta City is illustrated in Figure 2.

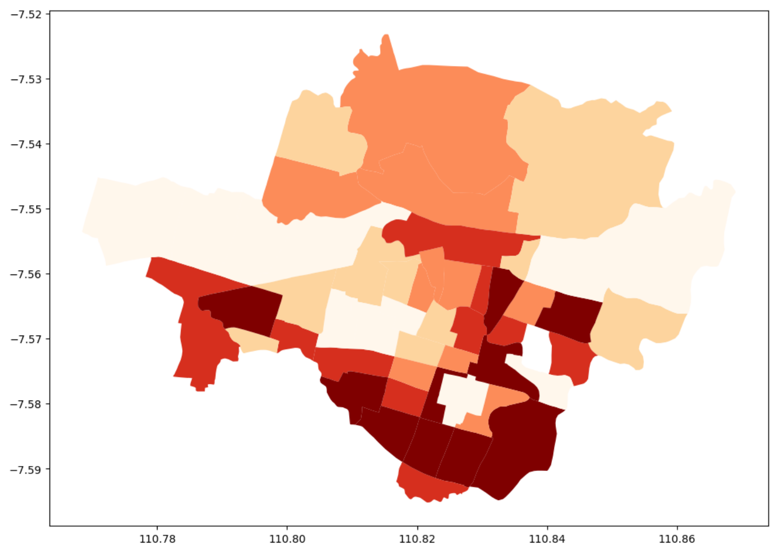

Figure **2.** Population density per neighborhood in Surakarta

The data regarding selected public facility locations in Surakarta City is divided into seven categories, namely shopping centers, universities, restaurants, supermarkets, Gasoline Stations (SPBU), and food courts. This data is visualized using the *Matplotlib* library to generate interactive maps. The data on public facility locations is utilized in the optimization process as one of the variables influencing charging demand. The map illustrating the distribution of selected public facility locations in Surakarta City is depicted in Figure 3.

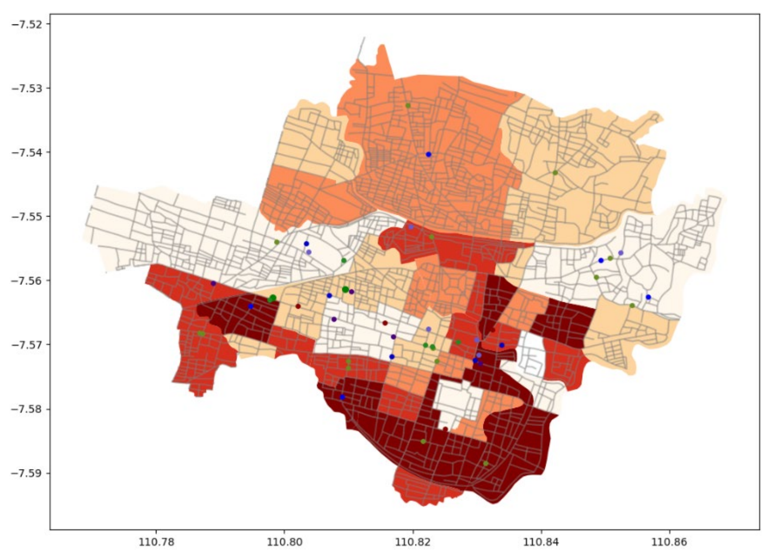

Figure **3.** Selected Locations of Public Facility in Surakarta

The provided paragraph discusses the findings derived from the collected data regarding electric motorcycle trips in different neighborhoods of Surakarta City. This information is presented through a visualization in Figure 4, indicating the distribution of trips across the city's neighborhoods. The data analysis has revealed that Jebres Neighborhood stands out due to its substantial number of electric motorcycle trips, suggesting a higher demand for charging services in this area. As a result, the proposition that Jebres Neighborhood should be prioritized for the establishment of PEVCS is supported by empirical evidence. This prioritization is logically grounded, aligning with the goal of optimizing charging station placements based on usage patterns.

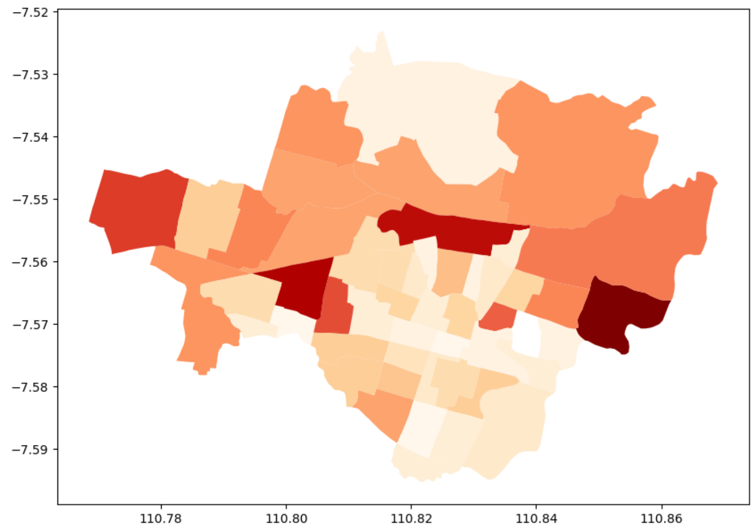

Figure **4.** Distribution Trips across the Surakarta's Neighborhoods

The data for Candidate Public Electric Vehicle Charging Station (PEVCS) locations in Surakarta City is employed to generate potential locations for constructing PEVCS in the city. This data is obtained by combining research data from "Optimizing Electric Motorcycle-Charging Stations Locations for Accessibility and Public Benefit: A Case Study in Surakarta" (Istiqomah et al. 2022) and data from several university locations, food courts, gas stations, parking areas, and supermarkets that can be utilized as PEVCS areas.

The paragraph outlines the process of refining the candidate locations for PEVCS using specific criteria within the web application. It begins by mentioning the integration of these locations into the application, which is then followed by the selection process considering travel routes and population density. This step serves to ensure that the selected locations align with travel patterns and user density. The paragraph then highlights the reduction from 35 initial candidates to 30, indicating the rigorous filtering that took place. These filtered locations are deemed optimal, with attributes that match the travel behaviors of electric motorcycle users and significant population density. The subsequent Cartesian coordinate plot visualization (Figure 5) showcases the remaining candidate locations, highlighting their distribution based on the composite weight of charging demand factors. Furthermore, the final step involves grouping these locations into 10 clusters (Figure 6), a strategy to streamline predictive estimation and improve location accuracy. This process underscores the commitment to identifying strategically viable PEVCS sites that are both convenient and well-frequented by electric vehicle users.

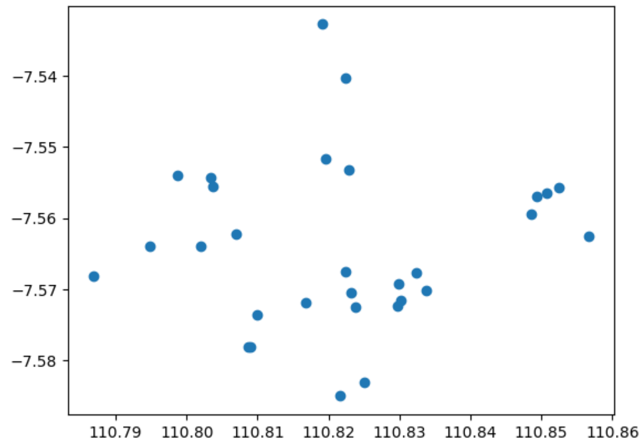

Figure 5. The Plot of Selected Candidate Locations based on Travel Routes and Population Density.

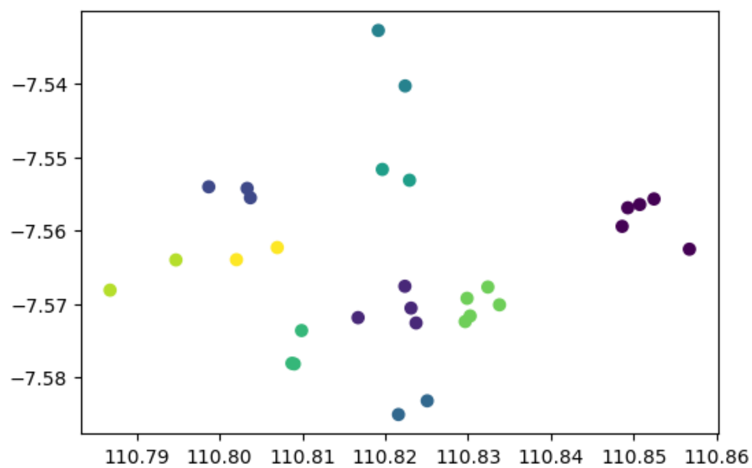

Figure 6. The Plot of the Clustered PEVCS Candidate Locations.

5. Results and Discussion

The provided passage highlights the critical outcomes of the optimization process within the research. It signifies the successful integration of data into the MILP-based optimization model to generate results that lead to optimal charging station locations. By formulating and applying suitable functions, the optimization process successfully identifies locations that satisfy both low travel costs and the capacity to meet charging demand. The paragraph emphasizes the screening process, which narrows down the original 35 PEVCS candidates to a final selection of 10 strategically distributed locations within Surakarta City. This reduction is informed by diverse data sources, including travel patterns and public facility locations, which altogether contribute to the robustness of the selection process. The visualization component is highlighted by mentioning Figure 7, showcasing the spatial distribution of these optimal PEVCS locations on a map, thus providing a clear and tangible representation of the research's achievements. Table 1 presents the list of optimal PEVCS locations in Surakarta City.

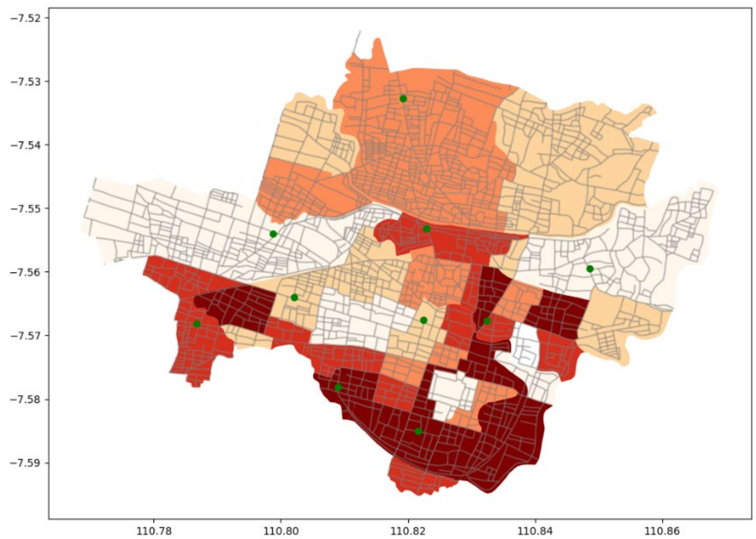

Figure 7. Map of Optimal PEVCS Locations in Surakarta.

Table 1. List of Optimal PEVCS Coordinate's in Surakarta.

No	Name of Optimal Location	Coordinate
1	SPBU Sekarpace	-7.559422 , 110.848602
2	Pura Mangkunegaran	-7.567589, 110.822379
3	SPBU Manahan	-7.554036, 110.798708
4	Danukusuman	-7.585071, 110.821603
5	Kadipiro	-7.532715, 110.819174
6	Gilingan	-7.553134, 110.822935
7	Duta BANGSA	-7.578174, 110.809026
8	Toko Asia Baru	-7.567697, 110.832393
9	SPBU Pajang	-7.568118, 110.786795
10	Indomaret Fresh	-7.563962, 110.802052

6. Conclusion

A supply chain network model has been devised to address the placement of electric vehicle charging stations within Surakarta City. This model is executed with the incorporation of several crucial factors, including the travel routes undertaken by electric motorcycle users across the city, the distribution of public facilities, population density data per neighborhood, and the identified potential charging station locations. Through this comprehensive model, invaluable insights are furnished to the local government, aiding them in making well-informed decisions regarding the optimal positioning of E-Motorcycle charging stations.

Nevertheless, it's essential to acknowledge a limitation inherent in this model. Namely, the current model does not encompass variables linked to the behavior of electric motorcycle users. As such, further research endeavors should address these limitations by employing a dynamic simulation model. Such an approach would allow for the inclusion of factors like queuing and charging time, thereby enhancing the model's accuracy and effectiveness in determining the locations for Public Electric Vehicle Charging Stations (PEVCS). This refinement would offer a more holistic perspective and contribute to the model's applicability and real-world relevance.

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