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Site Suitability Modeller Tool for Electric Vehicle Charging Stations by using the Integration of Hexagonal Fuzzy-AHP and GIS

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ABSTRACT

In this rapidly evolving landscape of urban mobility, a strategic deployment of Electric Vehicle Charging Stations (EVCS) holds key in the creation of sustainable transportation systems especially in the era of escalating demand towards the changes to an environmental sustainability. In fact, the uneven distribution of the existing EVCS causes several challenges such as range anxiety for users. These challenges require a strong approach in identifying suitable site. However, current practice shows limitation such as it may be prone to human errors. To address this, an automation tools are created, presenting an innovation methodology integrating Hexagonal Fuzzy Analytical Hierarchical Process (AHP) with GIS to conduct the site suitability modelling of EVCS. This approach involves five stages considering criteria like Perceived Safety, Accessibility, Public Facilities, and Population Density, based on Malaysian EVCS development standards. Spatial data representing the criteria need to be collected to establish nine criterion maps through data editing, rasterization, and reclassification processes. Weightage of each criterion were determined by using the pairwise-comparison matrix obtained from industrial and academician experts, followed by weighted overlay analysis to identify the suitable sites. However, this process can be tedious and lengthy which brings to the main objective of this study is to develop an automation GIS tool for site suitability modelling by leveraging specified criteria and weights provided by the experts. Ultimately, this tool aims to help in identifying suitable EVCS location with a single button thereby accelerating the deployment of EVCS and supporting sustainable urban transportation.

Keywords: EVCS; site suitability; hexagonal fuzzy-AHP; GIS; GIS automated tools.

1. INTRODUCTION

EV provide an affordable, environmentally friendly, and reducing dependency on fossil fuels to address climate change and sustainable transportation systems (Hernández et al., 2018). However, the major use of EV is dependent on the availability of a reliable charging infrastructure, necessitating on a comprehensive approach to determine site suitability for EVCS. This study aimed to identify potential sites based on various criteria including community impact, economic feasibility, environmental effects, and compatibility with urban planning goals (Ghosh et al., 2023). The main objective is to create GIS automation tool for locating suitable EVCS deployment sites. By integrating Multi-Criteria Decision Analysis (MCDA) with GIS, this study addresses challenges identified by the MyEVOC, including range anxiety and inadequate charging infrastructure. A better decision-making becomes possible by integrating MCDA with GIS which leads to dependable EV charging infrastructure. To accelerate the process of identifying suitable locations for EVCS deployment, this study aligns

infrastructure development with economic and environmental goals. This is by the creation of a Graphical User Interface (GUI) in a GIS software, as a tool that helps to evaluate the site suitability and gives benefits to developers. Through this development of comprehensive tool for EVCS site selection, it supports positive social change by promoting enhancing accessibility and equity, improving public health through reduced emissions, creating economic opportunities, and promoting sustainable practices (Li et al., 2022), in the same time addressing range anxiety with a reliable charging infrastructure.

2. METHODOLOGY

The research aims to tackle research question on how to measure the degree of importance of the criteria, suitable method, and how successful the tool in finding suitable location of EVCS. Figure 1 illustrates the methodology used to identify and develop tool for EVCS site suitability.

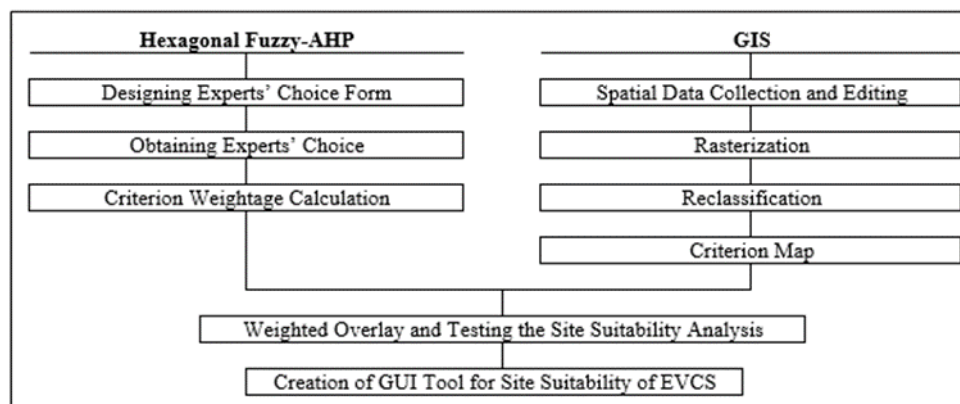


Figure 1. Research Flowchart

MCDA is a structured approach in making decisions when there are various criteria to be evaluated. Making a better decision, it is required to evaluate and compare alternatives using multiple criteria. However, uncertainties frequently occur in MCDA as a result of biased evaluations and ambiguous data that leads to difficulties in assigning weights to criteria (Malczewski et al., 2015). AHP is a widely utilized MCDA method that structures decision problems into hierarchical and involves pairwise comparisons to determine criteria importance through three different levels, goal, criteria, and alternatives (Saaty, 1987). The Fuzzy-AHP is the extended of AHP that helps in handling the uncertainties by introducing fuzzy logic, most commonly presented in matrices of three fuzzy number (FN) (Denis et al., 2000). However, Hexagonal Fuzzy-AHP offer more adaptable representation as it contains of six FN. The goal is to identify suitable EVCS location and develop a GIS tool with GUI. Criteria selection aligns with Malaysia's EVCS standards, involving nine criteria of street lights, pedestrian trails, public car parks, shop lots, malls, restaurants, public parks, sports arenas, and population density (Energy Commission, 2023). Pairwise comparison matrices determine criterion weightage based on the evaluation from academic and industrial experts. By the integration of GIS and MCDA, it enables precise site suitability evaluation using modern GIS modelling. The research involves data editing, rasterization, reclassification, creation of criterion map, assign weights into weighted overlay, and developing a tool for EVCS site suitability. However, this process is repetitive which tend to be lengthy and prone to human error. To address this, a tool was created by using ModelBuilder to automate all processes. Raw data for each criterion are required to be imported and final result are set in the tool. This approach eliminates the need

for manual process while making it more efficient and accelerate the process in identifying the site suitability for EVCS.

3. RESULTS AND DISCUSSION

Hexagonal Fuzzy-AHP is preferred for its capability in handling uncertainty and ambiguity in expert judgments, offering precise judgment through fuzzy linguistic terms suitable for complex decision-making. It surpasses traditional methods of AHP in providing higher precision for criterion weights. This study derive weightage based on experts' choice. The weightage are malls (20%), public car parks (15%), sport arenas (12%), public parks (10%), street lights (10%), population density (10%), pedestrian safety (9%), shop lots (8%), and restaurants (6%). The criteria and their weightage were then used in the modeller tool as fixed parameters as they are considered as the best practice in modelling the site suitability for EVCS. GIS automation enables the integration of custom scripts or GUI-based to streamline data imports and ensure consistency. Initially, the process starts with carrying out the process that were required. However, certain criteria require different processes, such as Euclidean Distance while others do not. To reduce mistakes caused by these multiple procedures and chain all processes together, a ModelBuilder need to be created, followed by the development of a tool for quicker site suitability evaluations. Since the process is continuous, one main dataset for each criterion must be imported and it is set as the parameter. The tool does not display intermediate process since the workflow is continuous. This tool simplifies the processes by presenting the output of the site suitability result. The name, data type, and filters are all configured correctly. Its success was evaluated with sample data from Shah Alam, Selangor. The developed model classifies site suitability using a colour scale ranging from least suitable (orange) to most suitable (dark green). Based on the result, the successful creation of the tool in a shorter timeframe demonstrates its potential use for wider range or other location.

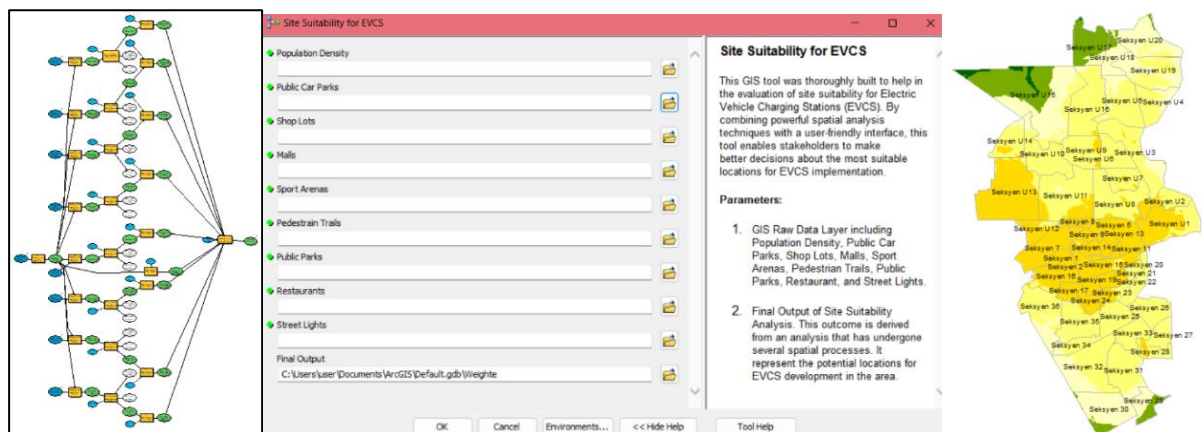


Figure 2. Model Builder, GUI of Site Suitability Tool, and Result Testing

4. CONCLUSION

In conclusion, the research integrates Hexagonal Fuzzy-AHP with GIS to determine EVCS locations effectively addressing challenges like range anxiety and inadequate charging infrastructure. The study highlights Hexagonal Fuzzy-AHP's effectiveness in handling uncertainty in criteria weighting. The successful implementation of the tool, demonstrates potential for widespread use, accelerating site suitability analysis. Generally, for research

purposes, this research provides a robust methodology that may be modified and expanded to include more criteria and advanced algorithms. On the other hand, the implication of the practices is that this research supports future advancements in sustainable infrastructure development. In reality, urban planners and developers may use this tool to make better, faster, and more accurate decision-making that ensures the efficient and equitable development of EVCS. For society, the adoption of this tool can benefit society by increasing accessibility and distribution, improving public health through reduced emissions, and encouraging sustainable practices that contribute to a more resilient and environmentally friendly transportation network. Future recommendations could focus on enhancing accuracy through real-time data integration and stakeholder collaboration for improving profitability and sustainable urban transportation initiatives.

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