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Location optimization for multiple types of charging stations for electric scooters

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ABSTRACT

The difference between traditional scooters and electric scooters is the convenience of refueling and charging process. Designing a complete infrastructure system is a necessary step if efforts to promote e-scooters are to meet with success. This study discusses the optimal location problem of locating charging stations—which is generally considered a location-allocation problem. There are two types of charging stations: charge stations and battery-exchange stations. The only one model in determining the location of either type of station tends to decrease the traditional utility compared to compound model traditional as this method tends not to set stations where they would serve the greatest number of customers. In addition, population density and land cost should be taken into account in determining where stations are set. We, therefore, propose a method that accounts for differences in population density and land cost in order to solve a multi-objective problem with maximum utility at minimum cost. A mathematical model is developed in which constraints pertaining to capacity and distance are considered. To find an optimal parameter for Multi-Objective Particle Swarm Optimization (MOPSO), generational distance (GD), maximum spread, spacing, and diversity metrics are applied. Finally, we research an angle-based focus method and determine the extent to which stations would be used in order to determine the optimal proportions of charging stations and battery-exchange stations. Moreover, according to the analysis we found that the installed ratio model of BES/BCS (Battery-exchange stations/Battery charging stations) is 6:5 in the downtown area and 1:6 in the outskirts of high population density areas. Besides, the BES/BCS ratio model is 1:13 in the downtown and only BCSs are installed in the outskirts of the low population density area.

1. Introduction

About 15 percent of manmade carbon dioxide comes from cars, trucks, airplanes, ships, and other vehicles. Reducing transportation emissions, therefore, is one of the most critical steps in fighting global warming. Environmentally friendly means of personal transportation such as electric cars, e-scooters, and electric bikes are among the solutions available and have become the subject of increasing attention as global warming has worsened. In particular, e-scooters may constitute a viable form of transportation given that they create less pollution than fuel scooters do [1]. However, in order to promote e-cars, e-scooters, and e-bikes effectively, it is necessary to consider not only the performance and efficiency gains associated with the power trains used in these vehicles but also the customer's experience.

There are two issues in regard to determining the location of BES/BCS systems: station type and station location. According to Wang and Lin [2], the main purpose of facility planning is that of determining the locations of multi-type stations, i.e., those that combine BES and BCS systems to that customers can access various stations and convenient battery refills. You and Hsieh [3] identified number, location, and type as three key parameters for stations that are necessary to consider in planning BES/BCS systems. They also concluded that location and station type should be given the most weight when stringent cost limitations are involved. Two cost limitations are discussed in the present study: the land cost of the location and the installation cost of battery-refill systems. Undoubtedly, the land cost is a fundamental issue to address in

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the location-allocation problem. Doong, Lai, and Wu stated that final location decisions are affected by various land costs associated with candidate areas. It should be expected, therefore, that land cost together with the installation costs of the two battery-refill systems, BES and BCS, are matters of great concern in location-allocation decisions. When only one type of battery-refill system is used at a station, however, the extent to which that station used can be expected to be limited.

In the present investigation, our goal is to understand the optimal facility location decision in regard to the highest numbers of times a station is used of the refill system. A hybrid refill system allocation in various land cost conditions can provide an optimal solution to the problem presented by the short battery life of e-scooters and the inconvenience of refilling, thereby providing a foundation for increasing the sale and use of this form of transportation.

This paper only focuses on the locations and allocations of battery-exchange station (BES) systems and battery-charging station (BCS) systems for e-scooters. Although charging and battery-exchange stations could provide services to almost all types of electric mobility devices, the assumptions and problems should be studied separately. The objective is to maximize the cover rate of electric scooters' customers instead of other types of electric mobility devices such as vehicles and bicycles, because maximum distance acceptable to customer for various mobility devices are different. For example, electric vehicles may have longer acceptable distance than electric scooters. Furthermore, the socket outlet, and required voltage are substantial different in electric mobility devices. The required power loading for the charging and battery-exchange stations is relatively small comparing to general electric cars. Charging electric scooters requires a regular household outlet of 115VAC, 15A, and produces about 1.5 kW, and the charge time is 7–30 h depending on battery size. Usually electric scooters prefer to have the battery-exchange service or overnight charging requirements. On other hand, electric vehicles require 230VAC, 30A two pole, and produces about 7 kW to charge a mid-sized electric vehicle in 4–5 hours. In this case, candidate locations such as convenient store, supermarket, and malls have the capabilities of setup the extra charging services using regular household outlet.

In the present study, we review the literature on the location-allocation problem, present a Multi-Objective Particle Swarm Optimization (MOPSO) algorithm, describe the design and verify our mathematical model and algorithm, and analyze the critical parameters and Pareto-optimal front. We also provide a conclusion and suggest directions for future research.

2. Related work

Cooper defined the location-allocation problem in terms of the need to provide goods or services to satisfy a spatially dispersed demand. Based on this definition, in regard to the subject of the present study, when there is a demand for battery-refill services at a large number of widely dispersed sites, it is usually impossible to provide the service everywhere. Therefore, it is necessary to engage in a process of decision-making aimed at effecting optimization in a continual way under cost limitation conditions. ReVelle and Eiselt identified four aspects that require consideration in addressing location problems: customers, facilities, a space in which customers and facilities are located, and a metric that indicates the distance between customers and facilities.

The objective function of the location-allocation issue depends to a great extent on the nature of the decision-making organization, i.e., whether it is public or private nature. In fact, trying to find the best locations for public facilities such as schools, parks, utilities, and sports and health centers is similar to the problem of selecting locations for private facilities, such as banks, shops, and private leisure facilities (Rahman and Smith). In general, there allocation problems comprise several aspects: minimizing impedance (P-Medium), maximizing coverage, minimizing facilities, maximizing attendance, maximizing the market share, and targeting market share (Hakimi [4], Toregas et al. [5], and Church et al. [6]). In battery-refill system location-allocation problem, different objective functions such as profit maximization, cost minimization, maximization of the demand served, and the minimum distance between customers and facilities can be considered. According to Upchurch and Kuby [7], most research to date applies the P-Median Problem and Maximal Coverage Problem models to refill-system location-allocation issues. They found that unnecessary facilities are opened in order to make the total distance between customers and facilities short when the problem is defined as P-Median Problem, even though there are limitations in regard to costs and/or the number of facilities that can be built. They recommended that research should be conducted by using the Maximal Coverage Problem model. As our study is conceptually similar to that of Upchurch and Kuby [7], we chose this model to develop our objective functions in order to minimize costs.

Kuby and Lim [8] used substitution and greedy substitution algorithms to maximize the demand served under conditions of limited capacity. Wang and Lin [9] used Branch and Bound methodology to solve the objective function of minimizing the cost of refill stations within the capacity limitation. Hanabusa and Horiguchi [10] solved the location-allocation problem from the point of view of both customers and decision makers. They balanced the objective of minimizing cost (from the customer's point of view) with the demand for electricity at each refill station (from the decision-maker's point of view) by applying the Dial algorithm. Lin adapted the algorithm to minimize the distance between customers and facilities in order to serve the entire population of a certain area. Wang and Lin [2] introduced the two stages of Branch and Bound to solve the multi-type refill system. In the first stage, the optimal capacity is found based on the minimized total installation cost. In addition, they compared the optimal capacity from the objective function of maximized coverage under a total installation cost limitation. Chen and Hua [11] minimized carbon emissions by using the LINGO solution to install Multi-type of refill stations. Gavranović et al. [12] applied CPLEX to minimize the distance between the customers and the facility. You and Hsieh [3] defined the various recharging-system types and obtained the shortest total distance between customers and recharging stations. They adapted GA methodology to serve the maximum number of customers considering multi-type recharging stations.

Moreover, Gang et al. [13] solved the multi-objective problem by adapting Adaptive Chaotic Particle Swarm Optimization (ACPSO) to the location-allocation problem. Their facility types vary by cost limitation. However, not only the cost of installing a facility need to considered, but the cost of the land must be considered likewise. In the present study, the location-allocation problem is defined as consisting of several factors relating to cost limitations: the cost of two battery-refill system types (the charge and exchange systems), the signal- or hybrid-type refill station, and the cost of land, which is designated as either high or low.

In a review of algorithms used for the purpose of location problems, Coello et al. [14] compared the optimal results derived by three algorithms—the Multi-Objective Particle Swarm Optimization Algorithm (MOPSO), the Pareto Archived Evolution Strategy (PAES), the Non-Dominated Sorting Genetic Algorithm (NSGA). In regard to performance time, MOPSO is always more rapid than that either PAES or NSGA. In seeking the optimal installation location and capacity of a distributed generator/capacitor, Zeinalzadeh et al. [15] compared the performance of four algorithms: MOPSO, the Strength Pareto Evolutionary Algorithm (SPEA), the Combination of