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Optimizing Tesla Charging Station Matching with Diverse Driver Preferences: Solving the Tie-Breaking Challenge

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Abstract: The rise of electric vehicles (EVs) has underscored a critical infrastructure challenge: the rather large difference between the growing need for charging stations and the number of them in existence. Existing allocation methods, which mainly involve proximity-based methods, do not take the variation of drivers into consideration, so there are inefficiencies. Specifically, this paper focuses on approaching the matching problem by the Gale-Shapley Deferred Acceptance (DA) method and its ability to untie the tie-breaking problem in preference-based systems for matching drivers with the Tesla charging stations. Thus, if AC factors include charging speed, cost, and the driver's urgency level, the DA algorithm will have a more efficient distribution of scarce resources for different requirements. More specifically, the study proves that with a higher level of matching, there is increased efficiency and justice in the distribution of charging stations, thus helping to improve the experience of the users and increase the utilization of resources.

Keywords: Tesla Charging Stations, Matching Algorithms, Driver Preferences, Tie-Breaking.

1. Introduction

The use of EVs has also come with several advantages in the areas of environmental conservation and cost effectiveness compared to internal combustion engine vehicles. However, this rapid growth has also highlighted a major issue: the charges to support these infrastructures have been insufficient to meet the growing customer demand. Such charging station allocation systems reflect on traditional strategies of locating them based on geographical regions and do not take into account the preferences of the EV drivers; for instance, fast charging, charge costs, and charging demands [1].

In this case, this paper intends to eliminate these drawbacks by applying an algorithm called Gale-Shapley Deferred Acceptance (DA) that has been recommended to solve the stable marriage problem to match drivers with available Tesla charging stations. Because of the ability of the DA algorithm to factor driver preferences, the process of assigning charging stations can be highly optimized and can be more easily fairly assigned. The more concrete research questions are as follows: how to incorporate the preference-based tie-breaking mechanisms most efficiently, and what consequences can be observed regarding system performance and drivers' satisfaction with the help of more advanced algorithms. Thus, this study will help to advance knowledge regarding the different factors that may influence the use of charging points by EV drivers and improve the satisfaction level of

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these users while also providing guidance for better deployment of scarce resources on the points required to meet the demand of users in the EV market.

2. Matching Algorithms in EV Charging

2.1. Demand and Challenges of Electric Vehicle Charging

The emergence of EVs is a revolution in the automobile sector due to the increased adaptation of environmentally friendly solutions in society. Some of the advantages of EVs include emissions of fewer greenhouse gases and lower costs of operation than ICEVs. However, the increasing popularity of EVs has exposed a critical infrastructure challenge: the tough competition between the increasing demand for charging stations and the scarce supply. Charging stations are not well dispersed, and several regions have inadequate provision or availability of the charging facilities, which results in wastage of the charging facilities [2]. In a country where charging stations are scarce, there are those who will not be particular about the type of charging station that they will use, be it a fast or standard charging station. Thus, assigning these stations in a random manner can cause some owners with no real need for them to control slots that are most precious for those who need to charge their cars as soon as possible[3]. The objective of this problem is to optimize the charging station and ensure that every driver has value for the scarce resource while at the same time avoiding wastage[4].

2.2. Matching Algorithms in EV Charging

Current solutions for matching the drivers to the CHWs, like those of Google Maps, follow a simple strategy that considers only the distance as the only factor affecting the driver's choice [1]. Despite the fact that this method helps to narrow down the search for nearby charging stations, it does not take into consideration the different options that drivers may be interested in, for instance, the charging speed or the cost of the service. This constraint leads to the inefficient and unfair distribution of the charging stations, which are a critical resource, thus worsening the available inequities[5].

The Gale-Shapley model, also known as the Deferred Acceptance (DA) algorithm, is one of the solutions to this problem. Originally developed to solve the stable marriage problem, Gale-Shapley's model can be used to match drivers with charging stations [6]. The DA algorithm operates with a process that entails making assignment recommendations for drivers and charging stations in such a manner that each assignment is stable and satisfactory to both parties. Hence, based on the driver's preference, the DA algorithm can be useful in providing the best solution for charging station placement[7].

Every driver will have his or her own preference when it comes to charging his or her EV. Some people may opt for the charging time whereas others may opt for the price or the convenience [8]. It is nonetheless conceivable to alter the DA algorithm in a way that would enable this variation in preference and hence arrive at a more efficient method of matching. For instance, if the driver is in a rush and requires a quick charge, he can be pointed to a fast-charging station and if the driver does not mind the time to charge the car then he can be directed to standard charging units [9].

2.3. The Role of Ties in Matching Drivers with Charging Points

The issue of ties in preferences occurs when drivers are indifferent between the fast and the slow charging stations. This creates a problem that, if not well addressed, can cause inefficiencies[10]. In the context of EV charging, these are tie-breaking methods that are used to address such cases and ensure optimal use of the available resources.

The tie-breaking mechanisms in the DA algorithm assist drivers in ranking their preferences to the extent of developing strict preferences when searching for charging stations; drivers are likely to state

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their real preferences for factors that are critical, such as charging speed, cost, and charging station accessibility [11]. For example, a platform may ask drivers to come up with their own ranking based on what they prefer, and therefore this will help to minimize the cases of ties and enhance the matching process [12].

3. Tie-Breaking

3.1. Implementation of Tie-Breaking Mechanisms

Charging capacities differ based on the kind of charging station that is being used. Superchargers by Tesla are an example of fast charging stations which are suitable for users who require to charge their cars as soon as possible [13]. While third-party chargers may have a combination of fast and standard charging, Tesla Destination Chargers are usually slower and best for longer stops according to Yong et al. [14]. Thus, by adding charging capacity constraints to the DA algorithm, the allocation process can be improved so that drivers are recommended the best charging stations that meet their requirements [15].

Another factor that is considered by drivers is the price of charging because they also like to save money. Owners of older Tesla models, on the other hand, do not have to pay for charging regardless of the location[13]. But for most EV owners, Superchargers are substantially expensive than home charging and thus may opt to charge at home if they still have enough charge [15]. The use of price preferences in the DA algorithm means that drivers can be connected to charging stations that have the prices that they can afford hence improving the effectiveness of the allocation process [16].

Some heuristics to break the ties within the DA framework might be to prefer the drivers who need charging and have less time to charge than the ones who can afford to wait longer [17]. This way, charging stations are given to the most deserving clients, which will help to avoid the misuse of the available resources [18].

3.2. Evaluation of Tie-Breaking Strategies

There are several ways through which one can assess the effectiveness of the various tie-breaking methods that can be used in a round-robin tournament, these may include; efficiency, fairness, and the satisfaction levels of the drivers. Efficiency on the other hand, entails the proper utilization of the charging stations so that drivers get the best alternatives that suit their needs [19]. Fairness is defined as the equal treatment of the drivers in terms of charging opportunities, so that no group of drivers is deprived of the chances more than the others [20]. Driver satisfaction in this case refers to the overall perceived experience that drivers have when using the charging system, factors such as waiting time, ease of use, and the convenience of the designated charging locations, as seen in[21].

Thus, comparing different tie-breaking methods can help to determine the advantages and disadvantages of each of them. For example, focusing on time-dependent factors may enhance the total system productivity, but at the same time, it may enhance the waiting time of less critical drivers [22]. On the other hand, if one takes into consideration other factors like the cost and charging speed, then the allocated resources may be distributed in a fair manner [12].

The following challenges emerge when developing the real-world matching algorithms and tie-breaking mechanism for the EV charging systems that are based on the advanced matching algorithms. One of the most important problems is determining drivers' attitudes toward the given types of charging methods. This implies that there should be easy-to-use interfaces and good ways of communicating with the drivers so that the drivers are able to input the right and detailed information about their preferences [5].

Yet another drawback is the integration of these algorithms with the presently used charging schemes. This includes the improvement of the current systems for the more complicated matching

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and guaranteeing that all the correct data is being collected and processed including availability in real time and charging rate [15]. In order to solve these problems and ensure the proper functioning of these highly developed matching systems, charging station operators, software developers, and policy makers should cooperate [16].

Also, there is an issue of confidentiality as the information collected will be based on the driver's preferences. Hence, it is important to ensure that this information is not accessible and the drivers' privacy is not invaded in order to win the confidence of users and hence make these systems go viral [22]. Improvements in data protection laws and correct ways of handling data should also help in minimizing these problems and enhancing the usage of complex methods in charging systems for EVs. Using the advanced matching algorithms and tie-breaking rules, the drivers' behavior can be influenced, and the functionality of the EV charging systems can be significantly enhanced. As a result, these systems can provide charging services that are more adequate to the drivers' needs and, consequently, increase the satisfaction of the users and the efficiency of the resources that are available [8].

For instance, drivers who find themselves in a situation where they need a fast charge and are still connected to a fast-charging station will definitely perceive the system to be good and will therefore continue using it. This can result in the overuse of certain charging stations and, therefore, an improved allocation of resources for the population [23]. At the same time, through the reduction of charging time and optimization of the waiting time, advanced matching algorithms can help reduce traffic congestion near charging stations and increase the effectiveness of charging infrastructure[12].

In addition, these systems can assist the drivers in organizing the charging of electric vehicles in a better way, which in turn enhances the performance of the system. For instance, drivers who understand that an appropriate charging station of their preference will be available may be more likely to adhere to the suggested schedules and charge their cars at the correct time, reducing the chances of charging at the last minute with all the consequences that may follow.

4. Conclusion

Charging point placement can make or mar and is one of several strategic decisions that should be made to use resources optimally. This research has shown that improvement is achievable by adopting sophisticated matching algorithms such as Gale-Shapley and Deferred Acceptance due to their unique consideration of the driver's preferences. The handling of the tie-breaking situation of the DA algorithm means that recharging stations are provided in a way that is most beneficial for the network and fair. These enhanced techniques offer better routing and dispatching as they allow matching based on other factors more relevant to the situation, for instance, the charging rate of the battery, the cost of the delivery, and in particular, the driver's need. Therefore, the work described here stresses the need to continue perfecting these algorithms and to implement them in practical applications to satisfy the demand for EV charging equipment. Therefore, as the use of electric cars advances, these advanced matching systems will be instrumental in optimizing the sustainability of charging resources.

This study also has policy implications for the efficiency of tie-breaking mechanisms in EV charging systems. The policymakers can guarantee the utilization of the enhanced matching algorithms, such as the DA algorithm, to enhance the effectiveness of charging station deployment[24]. Hence, with the available funding for research and development in this area, policymakers can be of great help in covering the current and future needs for the EV charging infrastructure while at the same time ensuring efficient use of the resources [24].

Further research might focus on the improvement of the DA algorithm and the tie-breaking rules to enhance consideration of the various preferences of EV drivers. This includes finding out how drivers can be engaged in a better way and coming up with other models that capture more features such as charging speed, cost, and access, among others[25]. Also, field studies and practice runs can be a good source of knowledge on how these algorithms can be used in real life and can also show potential problems and their possible solutions [26].

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