ELECTRIC VEHICLE CHARGING STATIONS OPTIMIZATION: A LITERATURE REVIEW AND PROSPECTS FOR SOPHISTICATION

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ABSTRACT

In contemporary society, depletion of fossil fuels and their impact on environment have shed light on the importance of moving toward vehicles that run on alternative-fuel sources. Among those vehicles the most promising and cutting edge in terms of sustainability and technology respectively are electrical vehicles (EVs). The adoption of EVs is considered a key driver on the way to the reduction air pollutions from the transport sector and improving environment in general. Proper development and deployment of EV infrastructure in cities across the world is paramount of importance for successful penetration of EVs in the market. This challenge has led researches to investigate possible ways for optimal location of EV charging stations that play a crucial role in the success of EV infrastructure. The optimal location for EV charging stations depends on a number of factors that include not only costs associated with charging EVs but also psychological issues such as range anxiety of EV drivers. In the literature, a variety of approaches, stochastic and deterministic variables, constraints and objective functions have been used in formulation of mathematical models that tried to address factors affecting integrity of EV infrastructure. In this article a review on the models - formulated on the basis of EV user approach -for optimal locating charging stations are demonstrated. Moreover, we present current research gaps and discuss possibilities that can be leveraged in further researches with respect to location selection of charging stations. Lastly, we show variables that should be considered in the formulation of models that are vital for increasing penetration of EVs in the market.

Keywords: electrical vehicles, charging stations infrastructure, literature review, optimal facility location, EV-user approach.

1. INTRODUCTİON

1.1 Importance of Electric Vehicles on the zero-emission pathway

Traditional internal combustion engine vehicles – which are brought into a motion by means of convertation of a fuel and air mixture – have recently resulted in severe air pollution caused by emission of a large amount of greenhouse gases in atmoshere. According to the International Energy Agency (IEA), in 2019 24% of the global emission associated with carbon-dioxide (CO2) accounts for the combustion of fuel by transport sector [1]. Skyrocket growth in air pollutants, such as CO2, hydrocarbons as well as nitrogen oxides, and recent changes in global climate lead to developement of the vehicles running on alternative energy sources, particularly the electrical energy. To be in line with objectives of the Paris agreement, the European cities has set a goal of deep decarbonization of road transport by 2050 [2]. To achieve the goal, cities across the world should minimize transport emissions and enhance the urban environment by establishing aggressive strategies. Additionally, they must achieve sustainability by making urban vehicle fleets environmentally friendly. Recent advancements in the automotive-making industry open space for production of vehicles running on alternative sources of fuel. In contrast to traditional fossil fuel vehicles, the alternative fueled vehicles allow to reduce not only greenhouse gas emissions (GHG) but also dependence on oil, which depletes swiftly and is in shortage in some countries. Variety of technologies exist that allow vehicles to run on alternative fuel sources. In the context of alternative fuel vehicles, the most promising and prevailing is electrical vehicles that brought into motion by means of electric motors.

EVs should provide a timely and feasible selection to a conventional automobile that utilizes fossil fuel. Even though currently electric cars are costly, they enable customers to save reasonable sums of money by lowering operation and maintenance costs. Nonetheless, it is essential to remove barriers and enforce strategies that foster high adoption of modern vehicles and increased adoption of EVs in urban road transport, as well as reduce the time required for adjustment from classic cars to EVs. Cities must embrace this imminent change in the transport sector, where EVs have a profound responsibility to achieve this goal.

1.2 Electric vehicles charging stations infrastructure

EVs are associated with low amounts of contaminants because they do not release harmful gases directly from burning fuel. Furthermore, they are highly efficient and economical compared to conventionally fueled vehicles. However, there is an emission of Greenhouse Gases during its construction, operation, and production of required electricity. They are more environmentally friendly, with 40% less carbon emission than traditional vehicles. Nonetheless, EVs use electric power; they possess batteries inside for energy storage and are rechargeable using a plug-in charger. Their significant challenges include recharging time and battery life that does not support use for long distances. The time required to charge an EV depends on the properties of the automobile, including the charging system type and technologies used. Charging areas can be positioned in homes, places of work, public areas, and private spaces. One of the significant success factors of the electro-mobility system is the ability to install chargers in public areas since it minimizes driver anxiety, which refers to the concerns of a driver over exhaustion of battery while away from their homes or places of work.

1.3 Objectives of the paper.

Recently, a vast majority of researches have been carried out in the literature related to the locating electrical vehicle charging stations. The common outcome of researches were mathematical models built upon certain assumptions with objective of locating EV charging stations in the optimal way. The aim of this paper is to provide a review on variety of model formulations developed by researchers in order to figure out best locations for EV charging stations from the EV user perspective. This paper mainly makes 3 contributions which are as follow:

1. A review on various model formulations that have aim at optimal placement of EV charging stations. Moreover, solution techniques and assumptions upon which these formulations have been developed are described in this paper.
2. Some existing research gaps in the placement of EV charging stations are determined and discussed.
3. Based on the conducted literature review, variables that are important in the formulation of mathematical models with the intent of determining optimal location for EV charging stations from the perspective of EV-users are analyzed and presented.

The rest of the paper is structured as follows. In section 2, we provide a literature review on the model formulations related to the optimal locating EV charging stations. In section 3, analysis of the literature is shown and important factors for formulation the models are identified and discussed. In section 4, current research gaps are demonstrated along with suggestions for further research and followed by a conclusion in section 5.

2. LİTERATURE REVİEW

Establishment of facilities generally is a matter of great concern for various public and private actions. Proper planning of parking spaces and establishment of fire or emergency places in the urban center solve challenges that may affect the optimal location of a facility. Furthermore, factors such as population growth, trends in the market, and other factors that affect the environment provide reasons for the change of location, extension, and adaptation of stations to ensure all needs are met at all times. Research on electro-mobility developed an interest in the challenge of the area. Hence, researchers suggested various optimization processes.

In the literature, three various approaches exist for determining the location of EV charging stations. The reason behind having various approaches is veiled in differences of the sentiment and objectives of key stakeholders which are investors of charging stations, EV drivers and electricity distribution network operators. The investors intention is to locate charging stations so that it would result in minimum installation cost and maximum profit. On the other hand, the EV drivers desire to charge their EVs in places that are easily accessible and results in minimum travelling costs, charging costs as well as waiting time. The operators, however, try to locate the charging stations to reduce the influence of them on the distribution system and to minimize costs associated with power loss, reliability, voltage stability and so forth. In the literature the approaches presented above are referred as Distribution network operator (DNO), Charging station owner (CSO) and Electric vehicle user (EVU) approaches respectively. According to a literature survey conducted by the Ahmad et al. [3] the least researched approached among aforementioned is the EVU approach, because only 4.35% of studies were focused on it.

The employment of EVU approach is more suitable if a decision maker seeks to increase penetration of EVs within a certain geographic area. The reason is EVU approach is directly related to the users of EVs for whom factors such as travel costs, waiting time and so forth are more important than the factors associated with the other two approaches. Moreover, one of the key drivers affecting level of EV market penetration is a phenomenon known as range anxiety, which is also referred as driver anxiety in the literature. According to Lee et al. [4], the range anxiety played a crucial role in slowing the rate of EV penetration in the market. The range anxiety is a driver concern with respect to running out of EV charge and consequently failing to complete a trip. The location of EV charging stations tremendously influences drivers' behavior with respect to the charging of their EVs.

Optimization algorithms used to address the challenge of the location of essential resources of EVs mainly depend on either maximization of covered demand or minimization of costs associated with traveling. Frade et al. [5] created a critical framework that addresses the ideal establishment of EV chargers in Lisbon. Charging requests in a day resulted from total jobs and the need for charging at night by entire homes in a given area.

Sweda & Klabjan [6] invented a decision support system that is agent-based to help in the placement of EV infrastructure. On the other hand, Hanabusa & Horiguchi [7] implemented a model that involved a two steps framework that depended on the assignment of traffic with stochastic balance for users and increment of entropy. This development ignored the aspect of traffic assignment and focused on demand at the beginning and end of the journey. Efthymiou et al. [8] utilized multi-criteria optimization while considering spatial attributes. The recommended method does not include the near-highest demand; however, it depends on an open-scoring model. Feng et al. [9] proposed an alternative framework for positioning stations on trunk highway. Wang et al. [10] suggested a planning framework with various objectives depending on the need for filling stations.

Worley et al. [11] implemented integer-programming representation for concurrent solutions for the challenges of vehicle routing and stations established for charging to lower total costs, including travel, recharging, and implementation. Chen et al. [12] implemented a mixed integer programming algorithm that utilized demand for parking as a proxy for the need for EV charging, with the primary objective of minimization the total access costs, while He et al. [13] adopted an active-set method in the ideal establishment of charging stations through plug-in hybrid vehicles to lower social welfare. Their paper aimed at formulating a strategic planning model. Research suggested that locations of public charging and charges for electricity are supposed to be considered at an early stage, i.e., during planning. Xi et al. [14], on the same, found that location is dependent on the criteria of optimization, unlike in-service levels. Sathaye & Kelley [15] sought to identify how stations can be located on corridors of highways. They created a continuous algorithm that reduces the deviation of vehicles from anticipated trips. Our method assumes that chargers can specifically be deployed in nodes.

Xu et al. [16] adopted a particle-swarm optimization algorithm to create a plan for optimal locating centralized charging stations with the objective of minimization of total travelled distance. Baouche et al. [17] formulated an exact model which was based on integer linear programming along. To formulate battery consumption profile in accurate way they applied dynamic consumption model from the VEHLIB library to the model. The suggested model seeks to lower vehicles' fixed-charge charging stations and travel costs. The authors computed the lowest time distance between demand clusters of an area and included information on consumption. Semi-fast chargers must be established in public parking places, while fast chargers should be installed in filling stations. Ghamami et al. [18] extended a capacitated fixed charge facility location model by incorporating factors such as unserved demand and preferences of driver in terms of parking lots. They formulated a model to determine optimal number of charging stations and locations where these stations should be deployed in existing car parks.

Sun et al. [19] sought to assess drivers' behavior by evaluating their EVs' remaining battery life and charge behavior through a stochastic frontier analysis. The optimization challenge in which the facility location and vehicle routing are resolved is the Location-routing process (LRP). Location and routing decisions vary because location decisions are strategic while routing is tactical. Several studies model LRM as an electric charger problem. Chen et al. [20] assessed the effects of locations established for charging on the performance of a network. They evaluated alternative sites for charging on the network's performance by including charging requirements in an equilibrium model constrained by distance. Lee et al. [4] created a bi-level optimization framework to reduce fail distance and the total time required for network travel. This method adopted a function of distribution of the remaining fuel ranger, which depended on probability. Jung et al. [21] adopted a stochastic queuing model, which was bi-level and aimed at establishing stations for charging electric taxis. Long et al. [22] suggested a a graph theoretic model that depended on demand and supply and aimed at lowering total costs which comprised of investment and operation expenditures. Likewise, Long et al. [22] formulated their model as mixed-integer-quadratic-programming problem. Under EV user driver approach, Yi et al. [23] has considered traveling, waiting and access costs in objective function for locating EV charging stations, while employing artificial immune algorithm as solution technique. Zhang et al. [24] and Tian et al. [25]

focused on the minimization of the social costs that included investment, electricity, operation and waiting time costs. The rest of the literature is summarized in table 1.

3. ANALYSİS OF THE LİTERATURE AND DİSCUSSİON

According to the literature, the model formulations with respect to the placement of EV charging stations can be classified and mainly analyzed by 5 variables, which are objective, charging station type, spatial scope, travel path and remaining range of EV. Depending on the scale of problem under consideration solutions techniques may vary. In case of implementing charging station infrastructure on large scale a lot of different solution techniques exist and can be employed to solve the model in a reasonable time. However, keep in mind that accuracy of solutions provided by the model may vary dramatically depending on a solution technique that was used.

Based on the table 1, it seems that most of models developed by the researchers had an objective of minimization of the EV trip failure distance. In other words, the models aimed at determining location for EV charging stations so that the number of EVs run out of the charge were as much as possible close to or at minimum. Deploying the charging station infrastructure with a focus of reducing number of EV trip failures is important because it would encourage prospective customers to purchase an EV and relieve range anxiety, which is considered as a key factor affecting penetration of EVs in the market. To achieve aforementioned objective, integration of remaining range of EV (RREV) in the models is necessary, because it allows to model EV driver behavior. According to the Franke and Krems [26] EV owner driving traits directly affect EV range consumption. On one hand, a risk-seeking driver would charge his or her EV when remaining range is not enough to complete a trip. On the other hand, a risk-averse driver would most likely to charge his or her EV at a higher remaining range in order to minimize the risk of not completing a trip. Therefore, simulation of EV driver behavior is paramount of importance in the development proper infrastructure for EV charging stations. Better estimate of charging behavior can be achieved by integrating in the model stochastic RREV variable rather than discrete counterpart of it. According to table 1, only two papers [4, 19] considered RREV to be stochastic. Of those 2 papers only study of Lee, Yong-Gwan, et al. [4] had objective of minimizing EVs' travel fail distance. In their study, they assumed that RREV follows either a triangular, a uniform or an increasing probability distribution function.

Another important variable to be considered in the formulation of location models for urban areas is travel path of EV. In most studies the travel path of EV assumed to be exogeneous. That is, all vehicles with the same origin-destination have been assigned to one path. In other words, all vehicles shared the same route. This assumption is often the case for intercity trips - which comprises trips between a pair of cities. The exogeneous determination of travel path is not suitable when charging stations are required to be deployed in urban areas. In addition, exogeneous determination of travel path prevents possibility of modelling detouring of EV drivers for charging and thereby distorts reality and reduces accuracy of solutions provided by a model. To better reflect reality and to model a driver behavior in more accurate way it is necessary to assume endogenous travel path, where the detouring decision of the driver will depend on the remaining range of his or her EV.

In overall it can be concluded that a few researches mainly concentrated on development of models that try to capture EV driver behavior's reason for integrating driver behavior in the models is its great impact on the penetration of EV and location of charging stations across a certain geographic area. This behavior is recognized in the models by incorporating factors such as EV battery consumption profile and possible detouring decisions of a driver in some cases. In addition, note that a vast majority studies are focused on the deployment of EV charging station infrastructure in urban areas, where GHG emissions from the transport sector prevail. This is also justified by the fact that most EV users are concentrated in those areas. We summarized variables which are vital for formulating a charging stations location model in Figure 1.

4. FURTHER RESEARCH

Examination of the literature in previous section explicitly points that endogenous travel path and probabilistic battery consumption profile are two assumptions necessary in developing models for proper planning and subsequent deployment of charging stations within an urban area. Nonetheless, a few research gaps exist in the current literature with respect to battery consumption of EV and its estimation in the models. The first research gap is related to the prediction of RREV, which basically represents battery consumption profile of EV and is foundation for studies related to the locating of charging station infrastructures. Among studies presented in the literature, more accurate estimation of RREV in the model has been done by the research of the Lee, Yong-Gwan, et al. [4], where they assumed RREV follows certain probability distribution functions. However, the assumption made by Lee, Yong-Gwan, et al. [4] can lead to unsustainable and less accurate solutions in the long-run given the fact that more cutting-edge batteries are applied to EVs as time passes. Recently a lot of studies have been carried out to developed techniques for more accurate estimation of battery consumption profile. In the literature related to prediction of battery consumption, two distinct approaches exist. The first tries to estimate the consumption by means of physical principles and is referred as knowledge-driven approach in the literature [27, 28]. The second approach is based on statistical analysis of data on the consumption of EV and is referred as data-driven approach in the literature [29, 30]. The former approach is generic but leads to large estimation errors. The latter approach is more accurate and less complex but difficult to extend to other EVs because it is based on the specific datasets that may have some drawbacks and not be comprehensive. To alleviate problems associated with aforementioned approaches and synergize their strengths, Ye, F., et al. [31] proposed a hybrid approach for estimation of battery consumption. According to results of experiments conducted by Ye, F., et al. [31], the hybrid approach indeed allows to improve prediction of battery consumption compared to the two approaches presented before. The Mean Absolute Scaled Error between measured and forecasted energy consumption of EV was not more than 2.5%. For further research we strongly suggest to investigate possible ways for incorporation of the hybrid approach in the models in order to increase accuracy of solutions with respect to the choice of location for charging stations and to enrich the literature.

The second research gap is that loads of the models incorporate only a particular type of charging equipment at a station or particular area. In practical terms consideration of different types of charging stations is necessary because it directly affects not only construction but also operating costs, which can be extremely high. In some occasions, drivers may prefer charging costs over charging time. Optimal locating only rapid charging stations can lead to discouragement of some, highly sensitive to costs, drivers from purchasing EV. Therefore, for further research it strongly advised to include all types of charging equipment (slow, semi-rapid, rapid and so forth) in the analysis of the EV infrastructure and to examine it influence on energy distribution network.

The third research gap is that all researches done in the literature do not consider land management which is conducted by government institutions. It is important for the reason that for almost all countries decisions with regard to the land management are taken on strategic level. In practical terms and EV infrastructure context it means that not all lands can be devoted used for the charging stations. For example, in Azerbaijan, lands are categorized and can be used for specific purposes based on their category. The rationality behind is to keep land balance, which can have a tremendous effect on economic health of country. Sustainable and efficient land management is necessary from not only economical but also societal and environmental perspectives. It would be interesting to figure out to what extent charging stations infrastructure could be affected if the land management concept had been taken into consideration in formulation of the models.

5. CONCLUSİON

In this paperwork, we performed an extensive review of the literature related to the charging station infrastructure, which is necessary for reduction emissions caused by the transport sector. For increasing penetration of EVs in the market a number of models based on the EV user approach have been proposed by researchers. It was shown that these models mainly can be categorized by five variables and solved by different techniques. We provided a discussion on these variables and presented in Figure 1 a framework for developing a charging station location model. Analysis of the literature explicitly showed that consideration of remaining range of EV and detouring-decisions of drivers is paramount of importance, because they allow to formulate more realistic models. It was also determined that aforementioned two factors were under researched in the literature. Examination of the literature also revealed three research gaps related to 1) estimation of battery consumption profile 2) types of charging stations and 3) land management issues. In addition, for each of these gaps a further research idea has been provided and their importance has been discussed.

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Study	Objective Function	Type of station	Spatial Scope	RREV	Travel Path
Sweda and Klabjan [6]	Identifying patterns in residential EV ownership and driving activities	DP	-	-	-
Hanabusa and Horiguchi [7]	Entropy maximization	EV	-	-	-
Wang et al. [10]	Multiobjective planning model	EV	-	-	-
Efthymiou et al. [8]	Multi-criteria optimization	EV	-	-	-
Worley et al. [11]	Minimize the total cost (travel, recharging and implementation)	EV	-	-	EXO
Xi et al. [14]	Maximization of EV service level	EV-S	-	D	EXO
Xu et al. [16]	Minimization of total transportation distance	CCS	-	-	-
Ghamami et al. [18]	Minimization of implementation cost	DP	-	-	-
Sun et al. [19]	Influence of charging infrastructure and battery technology on charging patterns of EV drivers	EV-R	-	P	-
Tian et al. [25]	Minimum travelling, waiting time and investment costs	EV-S	-	D	-
Zhang et al. [24]	Minimum travelling, waiting time, operating and investment costs	EV-R	-	D	-
Hodgson [32]	Minimum failure	DP	-	-	-
Ip et al. [33]	Minimum operational cost	EV	-	-	-
Ge et al. [34]	Minimum user's loss	EV	-	-	-
Wang et al. [35]	Maximum net income	BS	-	-	-
Long et al. [22]	Minimize total costs which involve investment and operation costs	EV	-	-	-
Chen et al. [20]	Minimize total system travel time	EV	-	D	ENDO

Wang [36]	Minimum number of stations	AFV	-	D	EXO
Kuby and Lim [37]	Minimum failure	AFV	INT	D	EXO
Kuby and Lim [38]	Minimum failure	AFV	INT	D	EXO
Kuby et. Al. [39]	Minimum failure	AFV	INT	D	EXO
Feng et al. [9]	Locating and sizing of charging stations on the urban trunk road	EV	INT	-	EXO
Upchurch et. al. [40]	Minimum failure cost	AFV	INT	D	EXO
Wang and Lin [41]	Minimum number of stations	AFV	INT	D	EXO
Kim [42]	Minimum failure	AFV	INT	D	EXO
Wang and Wang [43]	Minimum failure and construction cost	AFV	INT	D	EXO
Sathaye and Kelley [15]	Minimum charging infrastructure needs along highway corridors	EV-S and EV-R	INT	-	EXO
Kim and Kuby [44]	Minimum failure	AFV	INT	D	EXO
Capar and Kuby [45]	Minimum failure	AFV	INT	D	EXO
Frade et al. [5]	Maximum covering	EV-S	INN	-	-
Chen et al. [12]	Minimum access cost	EV-S	INN	-	-
Yi et al. [23]	User Charging Convenience cost, User Charging Cost and User Charging Time cost	EV-R	INN	D	-
Jung et al. [21]	Minimize the average delay, sum of travel time to facility, waiting time and service time.	AFV	INN	D	-
Baouche et al. [17]	Minimization of the fixed charge charging station and the vehicle travel cost	EV-S and EV-R	INN	D	ENDO
Lee, Yong-Gwan, et al. [4]	Minimum failure cost and network cost	EV-R	INN	P	ENDO
He et al. [13]	Maximization of the social welfare.	EV	INN and INT	-	ENDO

Note: - = not considered; DP = stations at destination points(convenience store, public parking spaces, workplace, and etc.); AFV = station for alternative-fuel vehicle; CCS = centralized charging stations; EV = station for electric vehicle; BS = battery switch station for EV; EV-S = slow-charging station for EV; EV-R = rapid charging station for EV; INT = intercity; INN = intra-city; D = deterministic; P = probabilistic; EXO = exogenously determined (all-or-noting assignment); ENDO = endogenously determined (user equilibrium assignment); remaining range of EV = RREV.

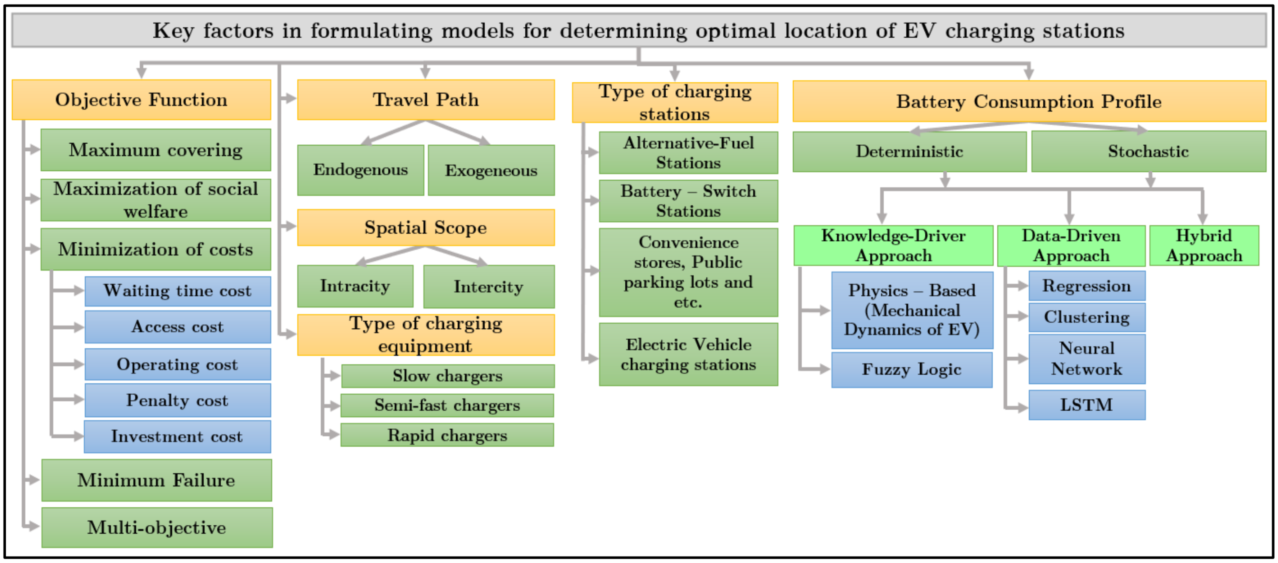

Table 1. **Summary of the literature review**

Figure 1. **Flow chart of factors needed in formulation of facility location models for EV**