Pamukkale Univ Muh Bilim Derg, 28(6), 802-811, 2022

Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

Placement and sizing strategies for dynamic wireless charging stations on signalized intersection corridors

Sinyalize kavşak koridorlarında dinamik kablosuz şarj istasyonları için yerleştirme ve boyutlandırma stratejileri

Erdem DOĞAN[1*]

[1]Department of Civil Engineering, Faculty of Engineering and Architecture, Kırıkkale University, Kırıkkale, Turkey.
edogan@kku.edu.tr

Received/Geliş Tarihi: 17.11.2021 Revision/Düzeltme Tarihi: 24.03.2022 doi: 10.5505/pajes.2022.90337
Accepted/Kabul Tarihi: 11.04.2022 Research Article/Araştırma Makalesi

Abstract

Dynamic wireless charging stations are a potential solution to the range problem of the limited battery capacity of electric vehicles. However, the infrastructure of these stations is costly, so it is important to position the wireless charging tracks (WCT) of the stations. This study proposes strategies in two different groups for positioning and sizing the charging stations on signalized corridors. The first group consists of two predefined strategies, while the second includes strategies using Gray Wolf Optimization (GWO) and Whale Optimization Algorithm (WOA). The performance of these strategies was tested taking into account various BEV ratios (r_{EV}) and maximum WCT lengths. Analysis results showed GWO and WOA is presented high-efficiency placement plans in the majority of cases studied. Surprisingly, however, with increasing r_{EV}, the predefined strategies showed better performances in some cases than that of GWO and WOA. Another notable finding is that the efficiency of the station can be increased by using more WCTs at the corridor entrances. This study presents results that have the potential to contribute to the solution of the problem of positioning and sizing wireless charging stations for intersection corridors and were not highlighted in previous studies.

Keywords: Dynamic charging station, Battery electric vehicles, Meta-heuristic optimization, Signalized intersection corridor.

Öz

Dinamik kablosuz şarj istasyonları, elektrikli araçların sınırlı pil kapasitesinin menzil sorununa potansiyel bir çözümdür. Ancak bu istasyonların altyapısı maliyetli olduğundan, istasyonların kablosuz şarj hatlarının (WCT) konumlandırılması önemlidir. Bu çalışma, sinyalize koridorlarda şarj istasyonlarının konumlandırılması ve boyutlandırılması için iki farklı grupta stratejiler önermektedir. İlk grup önceden tanımlanmış iki stratejiden oluşurken, ikincisi Gri Kurt Optimizasyonu (GWO) ve Balina Optimizasyon Algoritması (WOA) kullanan stratejileri içerir. Bu stratejilerin performansı, çeşitli BEV oranları r_{EV} ve maksimum WCT uzunlukları dikkate alınarak test edildi. Analiz sonuçları, incelenen vakaların çoğunda GWO ve WOA'ya yüksek verimli yerleşim planları sunulduğunu gösterdi. Ancak şaşırtıcı bir şekilde artan r_{EV} ile önceden tanımlanmış stratejiler bazı durumlarda GWO ve WOA'dan daha iyi performans gösterdi. Bir diğer dikkat çekici bulgu ise koridor girişlerinde daha fazla WCT kullanılarak istasyonun verimliliğinin artırılabileceğidir. Bu çalışma, kavşak koridorları için kablosuz şarj istasyonlarının konumlandırılması ve boyutlandırılması sorununun çözümüne katkı potansiyeline sahip ve önceki çalışmalarda vurgulanmayan sonuçlar sunmaktadır.

Anahtar kelimeler: Dinamik şarj istasyonu, Bataryalı elektrikli araçlar, Meta-sezgisel optimizasyon, Sinyalize kavşak koridoru.

1 Introduction

Battery Electric Vehicles (BEVs) have become an emerging player among modes of transport. In addition, factors such as fuel prices and increased environmental awareness suggest that the choice of engines based on fossil fuels will decrease significantly. On the other hand, the limited battery capacity and the longer charging time compared to fossil fuel-based vehicles are the major disadvantages of BEVs. A lithium battery pack contains 90-100 Wh of energy per kg. However, the same weight of gasoline has an energy of 12.000 Wh [1]. Increasing the battery size can be seen as a solution to overcome this shortcoming, but, this approach causes increased battery costs. As a further option, the development of battery technologies can be used to increase the capacity. However, this also has a similar effect in increasing the cost of BEVs. In this case, battery changing stations can be offered as an alternative in order to shorten the charging times [2]. However, there are still questions about regarding the long-term impact of this solution on batteries [3]. The Dynamic Wireless Charging (DWC) station is an effective technology to address these shortcomings. DWC technology, also known as Wireless Power Transmission (WPT) [4] and online electric vehicles [5], allows BEVs to charge their batteries in motion. DWC has important benefits like reducing driving range anxiety and lowering battery prices. In addition, a low battery capacity in a transportation network with continuous charging options is not a major problem [6]. Reducing the battery size of electric vehicles will also allow manufacturers to lower the selling prices of BEVs. In addition, the contributions of this system to social life can be listed as follows. BEV drivers save time because they don't have to stop to charge. The need for fixed charging stations is reduced, making dynamic charging stations a possible solution for areas with limited land resources. A physical charging cable is not required. This makes the charging process more convenient for BEV drivers.

The BEV population is forecast to grow by 36% annually through 2030 [4]. This growth clearly shows that the need for charging demand will increase significantly. Therefore, increasing the number of charging stations and improving the technology, as well as the appropriate distribution of these facilities over the electrified transportation network, will be a crucial task in order to maximize the amount of energy consumed by BEVs. This task can be modeled in three

*Corresponding author/Yazışılan Yazar

categories with regard to the characteristics of the construction site: Macro allocation model, micro allocation model, and provision at signaled intersections [7]. The macro model encompasses the entire city or region. Micro models determine optimal routes that connect important zones in order to provide charging stations. The charging efficiency increases at low vehicle speeds. For this reason, both macro and micro models identify signalized regions as potential station locations to increase charging efficiency [8]. Since the vehicle speed tends to decrease or approach zero in signaled corridors, and the charging process in these areas is referred to as quasi-dynamic charging [9].

The charging rate of a DWC station (DWC-S) increases with decreasing the driving speed of the BEV [10],[11]. A signaled intersection corridor on a motorway forces the flow of traffic to slow down. At these intersection corridors, the main flow of traffic is higher than on the ıntersecting streets and partially activated signal systems are suitable for controlling them. Therefore, these road sectors are convenient candidates for a quasi-DWC-S installation. A DWC-S is an expensive investment, and the construction costs are significantly influenced by the size of the Wireless Charging Track (WCT). WCT is a structure made up of electrical coils placed under the pavement, and these structures have connections with the other sophisticated units of the station. Therefore, solving the position and size problem (PSP) of the WCTs in a signalized corridor is a critical process in order to make the investment feasible. In the event of improper billing, moving becomes expensive, time-consuming, and problematic. In the literature, however, the arrangement of static charging stations has often been considered for road routes or road networks, but far too little attention has been paid to the placement of DWC-S on an intersection corridor. This study helps to close this gap in the literature by providing new knowledge for the establishment of a DWC system for installation in the signalized intersection corridor.

A proper WCT positioning and sizing strategy considering traffic flow characteristics will increase the system efficiency. Based on this concept, this paper investigates the usefulness of various WCT layout strategies on a signalized intersection corridor. Thus, this study aimed to address the following research questions:

a) Which strategy proposed in this study is suitable for a signalized intersection corridor for a PSP with a total WCT size constraint?

b) How does the rate of BEVs in the traffic flow affect the charging efficiency of the strategies?

c) How successful is the state-of-art optimization algorithms for solving PSP?

Regarding the above questions, the main achievements, including the contributions of this study, can be summarized as follows:

a) The results of this study reveal that with a WCT layout strategy that takes into account the character of the traffic flow can significantly improve the performance of the charging station compared to other strategies,

b) Semi-Actuated Signal Control (SASC) is a signaling system that minimizes interruptions in the flow of traffic in an intersection corridor. Unlike previous studies, this study uses SASC to control intersections and provides more robust insights for field applications,

c) The BEV rate (r_{EV}) in the traffic flow will not increase suddenly in the coming years. Therefore, in this study, the efficiency of the charging station was analyzed by working with different r_{EV}. The results of this analysis will contribute to decision-makers in determining a r_{EV} threshold for installing a charging station in an intersection corridor.

In today's world, the problems are complex and many decision variables and boundary conditions are needed to express these problems. Moreover, simulation-based optimization is required, especially for the solution of traffic engineering problems. To address these and similar issues, a significant number of nature-based heuristic algorithms have been developed over the past few years. Simulation-based approach and efficient heuristic algorithms are required for solving PSP. GWO and WOA are two state-of-art algorithms that have come to the fore in recent years, and the number of hyper-parameters they need is less than most other algorithms. For this reason, these two algorithms were chosen to be used in this study, and it was aimed to establish a reference by examining their solution performances in PSP. In further studies, more effective plans can be presented by comparing the results of various optimization algorithms with the results of this study.

The remaining part of the paper proceeds as follows: The related work examines critically important publications on charging stations and electric vehicles in the literature. Subsequently, Chapters 2 and 3 then briefly describe the WPT components and PSP, respectively. Chapter 4 describes in detail the 4 proposed strategies and illustrates their relationship to the PSP. Chapter 5 describes the simulation and parameter settings of the algorithms and the analysis results. Finally, in the sections Discussion and Conclusion, a criticism of the results and recommendations is given.

2 Related work

A recent study has examined the effect of wireless charging station location and proposed a new wireless charging scheme for signalized intersections [12]. The study has proposed a system planning that vehicles can smoothly cross signalized intersections using vehicle-to-vehicle and vehicle-to-intersection technologies and recharge, concurrently. The researchers have investigated the efficiency of the coordinated passage of connected and autonomous vehicles through intersections without delay, i.e., eco-driving and wireless charging simultaneously [13]. In the study, the locations of the coils have been planned without optimization, and it has been noted that the average amount of stored energy increased by 10%. A proposed bi-objective model has focused on the proper placement of wireless charging facilities, taking into account traffic delay and electricity gain from charging [14]. In addition to other previous studies, the authors have considered the effect of signal timings on charging capacity. The researchers have stated that it is not possible to optimize the delay and total charging energy at the same time. Therefore, they have proposed a semi-optimum model. In other words, the vehicle delays slightly increase, but the amount of energy received from the stations also increases. A major disadvantage of the study is that the vehicle type is not mixed, i.e. only BEVs. This fact makes it necessary to approach study findings with caution.

Minimizing infrastructure investment costs and charging costs are the primary goals of the DWC-S macro and micro deployment problems. Although dynamic charging facilities are more expensive investments than static stations, the authors have examined this situation economically and found interesting results [15]. According to this study, even with current technology, the probability of choosing dynamic charging increases significantly depending on the time value of the driver. Another study, which aims to minimize the investment costs for the wireless charging infrastructure, examined 39 important start-destination pairs in California [16]. The study has examined the road sections where DWC-S will be placed only based on vehicle range and has stated that the settlement optimization processes that can be done to increase the range can be done in future studies. The deployment optimization of plug-in and dynamic charging facilities for road networks with investment budget constraints was studied [17]. The study also includes the impact of travelers with different time budgets. The other studies proposed a deployment design model for DWC-S that aims to minimize the installation and charging costs [18]. The basic idea of the proposed model is that no BEVs run out of energy before reaching their goal. Placement studies were carried out by using hypothetical road networks and considering the constraints such as cost, etc. [19]. Other authors carried out benchmark tests on two hypothetical road networks for plug-in and DWC-S [20]. As a result of optimization processes, both types of stations are located close to intersections. A study was presented that optimizes the upper-level position of charging stations and formulates the user balance of route selection at the lower level [21]. This study was also performed for hypothetical road networks, and the results were similar to previous studies. The studies mentioned above, which were tested on road networks, also confirm that it makes sense to locate charging stations near network nodes, i.e. intersections.

Although numerous valuable publications and reviews have been published on this topic [22],[23]. the number of studies dealing with signaled intersections is limited. During studies whose study area is a road network, the nodes of the network are indicated as potential station locations. Further studies in these areas will help advance this research area.

3 Brief description of WPT components and development

There are two main approaches to near-field wireless energy transmission [24]. These are: (a) inductive WPT using coils connected by magnetic fields, and (b) capacitive WPT using plates. Both approaches include transmitter power electronics, rectifiers, inductors, compensation networks, high-frequency inverter capacitors [25]. DWC requires that road and vehicle elements to function mutually. The charging stations consist of various components, and the WCT is the main component applied to the road pavement. The WCT consists of laying coils or plates under the cover with Transmitter Power Electronics (TPE), as shown in Figure 1. These devices are powered by a power line that is properly connected to a local power grid.

The first steps in this DWC were taken with the Partners for Advanced Transit and Highway (PATH) project funded in 1986 [26]. PATH was a comprehensive project, and the first successful pilot tests of DWC were conducted. The first commercial application of DWC technology is the On-Line Electric Vehicle (OLEV) developed by the Korea Advanced Institute of Science and Technology.

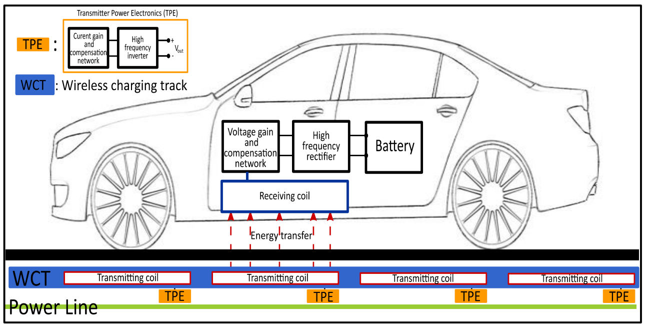

Figure 1. Road and vehicle components for dynamic wireless electricity transfer.

The first pilot implementation was carried out in the Seoul Grand Park. OLEV is currently operating in various cities in South Korea [26]. Various other organizations such as PRIMOVE, SELECT, FABRIC, ORNL, UNPLUGGED, and VICTORIA are also successful projects in this regard. In these projects, the EV battery capacities and the charging power of the stations used vary. The battery capacities range from 20 kW to 100 kW, and the charging power of the stations varies between 2.2 kW and 200 kW. The WCT lengths used are also between 36 m and 700 m. Therefore, this topic has a large number of variables and requires a considerable amount of research into the aspects of vehicle, energy supplier, road and user.

4 Position and size problem (PSP) statement

Variables that characterize traffic flow, i.e. speed, flow rate, and density, have the potential to affect DWC-S performance. On the other hand, there are a wide variety of variables, (i.e., Driver behavior, vehicle characteristics, corridor geometry, signal control, etc.) that affect the flow character. Capacity utilization rate in time $t, x(t)$, is one of the important variables among them, and it has a significant effect on the speeds of vehicles. Besides, the ratio of the number of electric vehicles in the traffic flow, r_{EV}, affects the amount of energy that a charging station will transmit over a time period T.

Let the traffic flow character is expressed by ξ, and ψ be the effect of variables other than these two variables (driver lane changing and car-following behavior, etc.). Thus, ξ in a signalized corridor can be expressed as:

$$\xi = f(\psi, r_{EV}, x(t)) \tag{1}$$

Let w_{ijk} expresses a WCT, and $i, j, k \in \mathbb{Z}^{+}$ express the index of an intersection, arm, and lane, respectively. The amount of energy (kWh) transmitted by a $w_{ijk}, e_{ijk} \in \mathbb{R}^{+}$, varies according to ξ, t, the longitudinal size of w_{ijk} ($s_{ijk} \in S$), the position parameter of w_{ijk} ($p_{ijk} \in P$) and the station charge power (ω). $S \in \mathbb{Z}^{+}$ and $P \in \mathbb{Z}_2$ refer to the size and position sets, respectively. The p_{ijk} expresses the decision of w_{ijk} placement on the road lane k. Thus, e_{ijk} can be written as:

$$e_{ijk} = f(\xi, \omega, T, s_{ijk}, p_{ijk}) \tag{2}$$

The purpose of this study is to determine convenient s_{ijk} and p_{ijk} vectors that will maximize the amount of total energy transmitted by WCTs (TE) based on their size. The problem of setting WCT positions and size in the signalized intersection corridor can be formulated with the variables described above as follows:

$$\text{Maximize: TE} = \sum_{i} \sum_{j} \sum_{k} (p_{ijk}.e_{ijk})$$
$$\text{Subject to: } minTL \leq \sum_{i}^{nI} \sum_{j}^{nA_i} \sum_{k}^{nL_{ij}} s_{ijk} \leq maxTL \quad (3)$$

Where, $minTL$ and $maxTL$ refer to the minimum and maximum values of the search space, respectively, i.e., they are the lower and upper limits of the total length of the WCTs (TL) to be positioned in the corridor. nI, nA_i, nL_{ij} express the number of intersections in the corridor, number of the arm in intersection i, and number of the lane in arm j and intersection i, respectively.

5 Solution methodology of the PSP

Many studies discussed in Section 2 show that low-speed profiles in signalized intersection corridors enable an improvement in charging efficiency. Thus, WCT planning should be performed by considering the traffic flow and control characters together for these corridors. This section describes WCT positioning and sizing strategies in two groups (Group A and B) for the signalized intersection corridors. There are two different approaches in Group A, and they are based on a predefined distribution plan (A-1 and A-2). On the other hand, Group B is based on state-of-art heuristic optimization methods, namely: Grey Wolf Optimizer (GWO), Whale Optimization Algorithm (WOA). The pre-definition of Group A strategies has the potential to simplify the planning and installation phases on site. On the other hand, the performance of these strategies should be used with caution in different traffic and intersection conditions. The disadvantage of Group B is that heuristics can take longer to reach the global optimum or tend to get stuck in a local optimum. Additionally, the optimization process can suggest a layout that is too complex to implement in the field if the problem constraints are not adjusted without careful consideration of the site geometry and electrification infrastructure.

5.1 Strategy group A

Group A strategies ensure that the WCT sizes are equal for each intersection, but meet the precondition with different variations. A1 positions the WCT in one of the through lanes of the intersection's main street, and this lane is named as WCT lane. As it is assumed that there is low traffic demand on the side street of an intersection, A-1 is not place any WCT on the side street. A1 calculates the longitudinal WCT size for a corresponding lane, using Eq 4.

$$s_{ijk} = \frac{maxTL}{nI.nA_i} \quad (4)$$

Strategy A2 positions the WCT in each lane on the main street, except auxiliary lanes, and sets the longitudinal length of each WCT (s_{ijk}) equally using Eq 5. The symbols used in Eq 4 and 5 are explained in Section 4.

$$s_{ijk} = \frac{maxTL}{nI.nA_i.nL\kappa_{ij}} \quad (5)$$

Modeling the amount of energy that the proposed strategies transfer under the given conditions is a very complex process, as the flow of traffic is influenced by a large number of random variables. It is therefore common in traffic engineering to use microsimulations for modeling. On the other hand, microsimulation makes this process easy for the user and provides results with sufficient accuracy for comparison. Figure 2 illustrates the relationship between the strategies and variables in Group A when simulating the total amount of energy that WCTs transfer to BEVs.

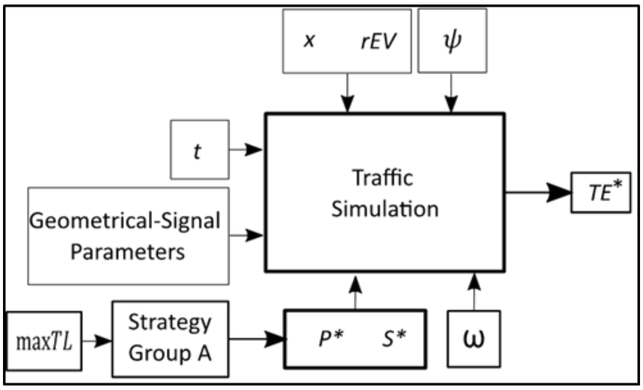

Figure 2. Relationship of Group A strategy with variables and simulation.

In Figure 2 and 3, P^* and S^*refer to the decision sets that a strategy proposes for positions and sizes, respectively. TE* indicates the TE obtained as a result of using P^* and S^*. The geometric and signal parameters include the number of intersections, arms, and lanes in the signalized corridor, distances between the intersections, and the settings of the signal management system. The charging power, efficiency rate, charge delay parameters of the WCS are considered constant and expressed as ω.

The strategies in Group A predefine the P and S sets and adjust the WCT lengths equally for each intersection in the corridor. This approach is a simple and general solution that can be suggested for the PSP problem. The advantages of Group A strategies are: The computational effort to determine and the installation of the system in the field can be less complex than strategies that suggest different WCT lengths.

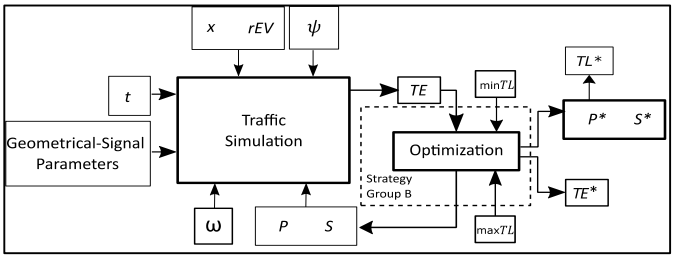

Figure 1. Relationship of Group B strategy with variables, simulation, and optimization process.

5.2 Strategy group B

Intersection corridors have different geometric properties and traffic flow characteristics. Therefore, the lane position and the size of the WCTs should be adjusted individually for each intersection. However, a large number of intersections and the lanes in the corridor make this problem an NP-hard. Meta-heuristic approaches have the potential to suggest appropriate solutions in reasonable computing time for Np-hard problems. Group B strategies were designed to take advantage of this superiority, and their general stages are illustrated in Figure 3. In the first step of the procedure, the decision-maker determines the $minTL$ and $maxTL$ constraints for the optimization process. The optimization method creates

P and S sets using the constraints and transmits them to the simulation as shown in Figure 3.

The values of other variables and constants (geometric and signal parameters, t, x, r_{EV}, etc.) have also been added to the simulation. The traffic simulation calculates the traffic flow, the signal times, the charge amount of BEVs, and finally determines the TE value for the proposed P and S sets. The optimization algorithm evaluates the TE, considering the PSP's constraints and the algorithm's stop criteria, and decides to create new solution candidates for the next iteration or to terminate the process. As a result of the decision to terminate the iterations, the algorithm presents the P^* and S^* sets as results.

The purpose of using a metaheuristic algorithm to solve the PSP problem is to adjust the WCT positions and sizes taking into account the traffic characteristics of the corridor. This maximizes the efficiency of the DWC-S installed in the corridor. A variety of optimization algorithms are proposed by researchers today. Swarm-based optimization algorithms that are inspired by nature are often preferred for solving similar problems due to their simplicity, flexibility, their derivative-free mechanism and their local optimal avoidance [27].

In this study, two state-of-the-art algorithms were selected to be utilized as optimization methods, namely: Grey Wolf Optimizer (GWO) [27], Whale Optimization Algorithm (WOA) [28]. These methods include swarm-based algorithms. They search for the optimum solution to the PSP problem by using the collective intelligence of the groups in the solution space. GWO and WOA were compared with other well-known heuristics algorithms (Particle Swarm Optimization, Gravitational Search Algorithm, Differential Evolution, Evolutionary Programming, and Evolution Strategy) in the original articles [27],[28], for different engineering, physics, and benchmark problems, and the solutions of GWO and WOA proved to be superior. Based on these results, it was decided to use GWO and WOA to solve the problem in this study. SUMO has a lot of support code written in the Python programming language for solving various problems. The GWO and WOA codes were used with SUMO to optimize the PSP problem [32].

5.2.1 Grey wolf optimizer

GWO is a swarm-based algorithm that has been gaining attention recently. Some researchers have presented studies on BEVs charging using GWO [29]-[31] GWO searches for a problem solution by mimicking the hierarchical structure and hunting tactics of gray wolves. The hierarchical structure of gray wolves is defined by alpha (α), beta (β), delta (δ) and omega (ω), and the α wolf is at the top of the hierarchy. The hunting process of the gray wolf pack consists of three main steps. These are the pursuit of prey, chase, and encirclement, and finally attack.

The following equations are proposed to mathematically model the encirclement behavior of a grey wolf. Let $\vec{X}_p(t)$ be the prey position, and $\vec{X}(t)$ be the wolf position at time t. Then, the distance between prey and grey wolf and the updated position for $t+1$ of the wolf:

$$\vec{D} = \left|\vec{C}.\vec{X}_p(t) - \vec{X}(t)\right| \tag{6}$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}.\vec{D} \tag{7}$$

Where $\vec{A}$ and $\vec{C}$ indicates coefficient vectors, and they are calculated as:

$$\vec{A} = 2\vec{a}.\vec{r}_1 - \vec{a} \tag{8}$$

$$\vec{C} = 2.\vec{r}_2 \tag{9}$$

Where $\vec{r}_1$ and $\vec{r}_2$ are random vectors in the range [0,1] and $\vec{a}$ is a vector that linearly decreased from 2 to 0 through iterations.

The GWO manages the hunting process according to the wolves' position, which is at the top of the hierarchy (α, β, δ). Because the GWO assumes that these wolves are better predictors of the location of the prey. Other wolves update their positions according to these superior wolves. The mathematical expressions of a wolf's distance from superior wolves and its updated position, $\vec{X}(t+1)$, are modeled in Eq 10-12.

$$\vec{D}_\alpha = \left|\vec{C}_1\vec{X}_\alpha - \vec{X}\right|, \vec{D}_\beta = \left|\vec{C}_2\vec{X}_\beta - \vec{X}\right|, \\ \vec{D}_\delta = \left|\vec{C}_3\vec{X}_\delta - \vec{X}(t)\right| \tag{10}$$

$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1.(\vec{D}_\alpha), \vec{X}_2 = \vec{X}_\beta - \vec{A}_2.(\vec{D}_\beta), \\ \vec{X}_3 = \vec{X}_\delta - \vec{A}_3.(\vec{D}_\delta) \tag{11}$$

$$\vec{X}(t+1) = \frac{(\vec{X}_1 + \vec{X}_2 + \vec{X}_3)}{3} \tag{12}$$

The gray wolf hunt ends when the prey stops, and the pack attacks the prey. $\vec{A}$ takes values in the range [0,1] during the iteration, and decreases due to the linear decrease of $\vec{a}$. When the $|\vec{A}| < 1$, the pack attacks the prey, i.e., the optimization process ends. A detailed explanation of GWO, enhanced with visuals, can be found in the original work [27].

5.2.2 Whale optimization algorithm

WOA was developed inspired by the specific hunting behavior of humpback whales. This unique hunting behavior of humpback whales is called bubble-net feeding [32]. In this technique, the whales first dive under the prey. Then, they start to swim spiral shape upwards while forming air bubbles. Mirjalili and Lewis explained in their original work the mathematical model of the WOA in three steps: encircling prey, spiral bubble-net feeding maneuver, and search for prey [28]. For encircling prey, the location of the prey must first be determined. WOA creates a population that includes solutions. Next, WOA assumes that the best candidate solution is closest to the target. Thus, the location of the prey is determined hypothetically.

Let, $\vec{X^*}$ be the best solution obtained so far, and $\vec{X}$ be the position vector. Let $\vec{A}$ and $\vec{C}$ indicates the coefficient vectors. $\vec{X^*}(t)$ is checked at each iteration step. If a new best solution candidate emerges, $\vec{X^*}$ is updated using the value $\vec{X}(t+1)$. Thus, the distance between $\vec{X^*}$ and $\vec{X}$ is denoted as:

$$\vec{D} = \left|\vec{C}.\vec{X^*}(t) - \vec{X}(t)\right| \tag{13}$$

According to the position of $\vec{X^*}$, $\vec{X}$ updates their positions at iteration $t + 1$ using Eq 14:

$$\vec{X}(t+1) = \left|\vec{X^*}(t) - \vec{A}.\vec{D}\right| \tag{14}$$

$\vec{X^*}(t)$ is monitored at each iteration step. If a new best solution candidate emerges, $\vec{X^*}$ is updated using the value $\vec{X}(t+1)$. The value of A is depending on a vector a and r. The a value is decreasing linearly over the iteration, and r has random values in [0,1]. The vectors $\vec{A}$ and $\vec{C}$ are calculated as follows:

$$\vec{A} = 2\vec{a}.\vec{r} - \vec{a} \tag{15}$$

$$\vec{C} = 2.\vec{r} \tag{16}$$

Once the prey location is determined $|A| < 1$, the whale attacks its prey using the bubble net method. This method is modeled mathematically in two behaviors: shrinking encircling mechanism, and spiral updating position. The shrinking encircling mechanism mathematically mimics the spiraling motion of humpback whales. This mechanism works by decreasing the value of $\vec{a}$ mentioned in Equation 20. As a result, the value of $\vec{A}$ fluctuates and the range of motion of the prey shrinks.

The spiral update position behavior involves modeling the positions of the whales during their helix-shaped movements. Let b be the constant, and l be the random number in [-1,1]. Hence, the updated position vector of the whale is as follows:

$$\vec{X}(t+1) = \vec{D'}.e^{bl}.\cos(2\pi l) + \vec{X}(t) \tag{17}$$

$$\vec{D'} = |\vec{X^*}(t) - \vec{X}(t)| \tag{18}$$

The upward spiraling behavior of the whale has been modeled using these two attitudes, and the random number, p [0,1] as follows:

$$\vec{X}(t+1) = \begin{cases} \text{if } p < 0.5 & \vec{X^*}(t) - \vec{A}.\vec{D} \\ \text{else} & \vec{D'}.e^{bl}.\cos(2\pi l) + \vec{X}(t) \end{cases} \tag{19}$$

The researchers suggest $p = 0.5$ to equalize the probability that the approaches will occur during optimization.

WOA searches globally before taking the prey into the net, i.e. when $|A| > 1$. This behavior is expressed in the following formulas.

$$\vec{D} = |\vec{C}.\overrightarrow{X_{rand}} - \vec{X}| \tag{20}$$

$$\vec{X}(t+1) = |\overrightarrow{X_{rand}} - \vec{A}.\vec{D}| \tag{21}$$

Where, $\overrightarrow{X_{rand}}$ is the position vector of the whale randomly selected from the solution population. The WOA steps continue until the specified number of iterations or termination criterion is met.

5.3 Measure of efficiently

The total amount of energy transferred from WCT to BEVs is an important measure of efficiency, but the TL^* offered by Group A and Group B strategies for the same situations differ, as discussed in previous chapters. Thus, instead of TE^*, the energy amount transmitted by the unit length of WCT to BEVs (ε), presented in Eq 22, was used to compare strategies.

$$\varepsilon = \frac{TE^*}{(TL^* \text{ or } maxTL)} \tag{22}$$

The TL^* is the recommended total WCT length from optimization algorithms, and this value is usually slightly below the $maxTL$. Therefore, $TE^*$is divided by $maxTL$ in Group A and by TL^* in Group B for the calculation of the ε.

6 Computational study on strategies performance

6.1 Simulation setup

A corridor consisting of three consecutive intersections illustrated in Figure 4 was used for comparisons. This type of corridor is common in road sections where highways intersect with secondary roads, and Semi-Actuated Signal Control System (SASC) is suitable for these road sections.

A SASC system ensures that the main traffic flow in an intersecting corridor has a right-of-way unless there is adequate secondary traffic flow. For these reasons, SASC is a suitable signal control option for corridors consisting of a main artery and low-flow secondary roads.

SASC works with the help of detectors placed on secondary roads. Vehicle spacing information collected from these detectors is processed by the algorithm used by SASC, and the phase sequence is determined. Thus, the main traffic flow is less interrupted and the junction delay is reduced. Detailed information can be obtained from various studies on this subject [33],[34].

Only 2 phases are used in SASC and left-turns are restricted in simulations. The signal control parameters, such as green time for phase 1 (g1), yellow time (y1), the minimum and maximum green duration for phase 2 (minimum Duration (minDur) and maximum Duration (maxDur)) were calculated based on the volume/capacity (v/c) ratio profiles are illustrated in Figure 4(b). The capacity of the intersection approach refers to the maximum traffic flow that can be achieved based on the green time allowed by the controller to the road lane.

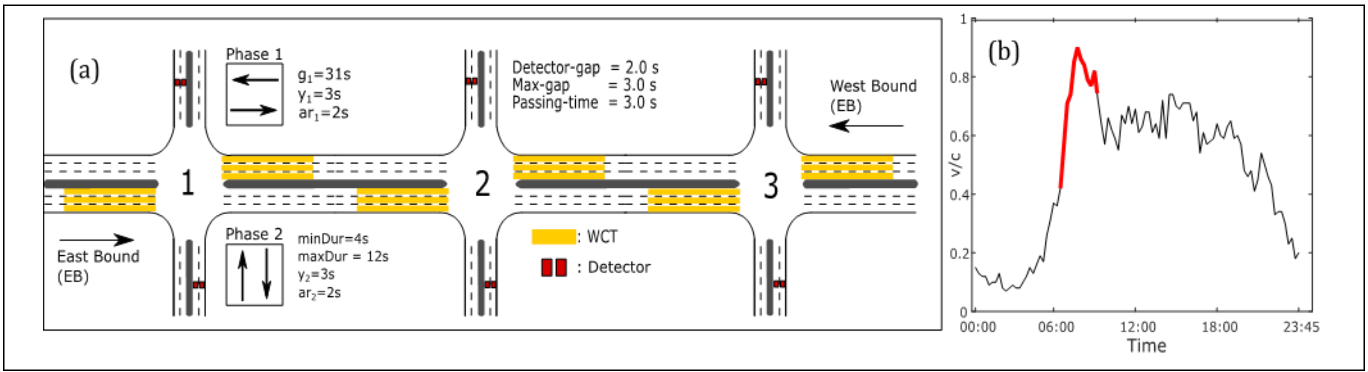

Figure 2(a): Corridor geometry and components, and signal control system features. (b): The oscillation of a daily traffic flow/capacity ratio used in simulations.

Volume, on the other hand, is the number of vehicles that want to pass through this approach in a given time interval. Capacity and volume depend on various factors such as traffic conditions, road geometry characteristics, environmental factors, etc. The time resolution of the traffic flow profile is min and its peak-hour is at 07:15-08:15.

In the simulations, the T=3-hour traffic flow profile including the peak hour (Figure 4b red line) was utilized to generate the flow. The simulation thus covered both the peak hour and the period with relatively low v/c ratios. This traffic flow profile refers to $x(t)$ in the PSP problem.

This network was analyzed using SUMO traffic simulation [39]. SUMO offers a wide range of options to define vehicle characteristics and driver behavior. In this study, the Krauss model [40] was used to the model car following, and the DK2008 for modeling the lane changing behavior. These two models refer to ψ in Equation 1. The accuracy of the results obtained in a study is directly related to the reliability of the selected micro-simulation program. A robust program alone is not enough. Therefore, simulation should be calibrated for prevailing traffic conditions before starting real applications. Calibration was not performed for this study due to the use of a hypothetical corridor.

In this study, heterogeneous traffic flows including fossil fuel-based cars and BEVs are modeled. Thus, the effect of r_{EV} on DWC-S efficiency could also be discussed. The r_{EV} rates are considered as low, medium, high, and very high ratios were used as 0.1, 0.3, 0.5, and 0.7, respectively. The power and efficiency of the charging station are important factors affecting the total amount of energy transmitted. The power of the charging stations was assumed to be 22 kW and their efficiency is set to 0.95 [35].

6.2 Parameter setting of PSP and optimization algorithms

This section introduces general parameters that are used in strategies of groups A and B, as well as selected parameters for optimization algorithms. The critical parameters, $maxTL$. The $maxTL$ for Group A is calculated considering the cases where the WCT length in each approach lane is 25, 50, and 75 m for the A-2 strategy. Because A-2 places WCTs of equal length in all lanes. In the hypothetical corridor, there are 18 lanes for placing the WCT (Figure 4(b) yellow stripes). Thus, $maxTL$ is calculated as 25×18=450, 900 m, and 1350 m. A WCT with a length of 100 m was also desired to be used in simulations. However, in this case, the 300 m WCT length could not be applied for the A-1 strategy because it was longer than the approach arm length. GWO and WOA use the epoch, search agent numbers, and parameter as inputs. Other parameters are automatically updated with random values and according to the output value during the entire iteration. There is no clear recommendation in the literature for the selection of these parameters. However, in the original articles, values between 5-100 for the number of search agents and 50-1000 for the maximum number of iterations were tried for the engineering problem [27]. The study states that the GWO shows very rapid initial convergence for global exploration in the first 50 iterations. WOA, on the other hand, shows the first convergence in 50 iterations for many problems, too. Based on this information, 30 were utilized for the search agent number and 50 for the epoch number. Additionally, both studies point out that $a = 2$ is appropriate for most problems. Therefore, $a = 2$ was selected for The optimization process terminated the completion of the iterations.

6.3 Comparison of strategies results

This section evaluates the performance of the site plans proposed by the strategies using different $maxTL$ lengths and applying r_{EV} ratios in the corridor. Therefore, the effectiveness of the strategies for 12 cases was compared and the results of the simulations are shown in Figure 5, which are used as performance measures.

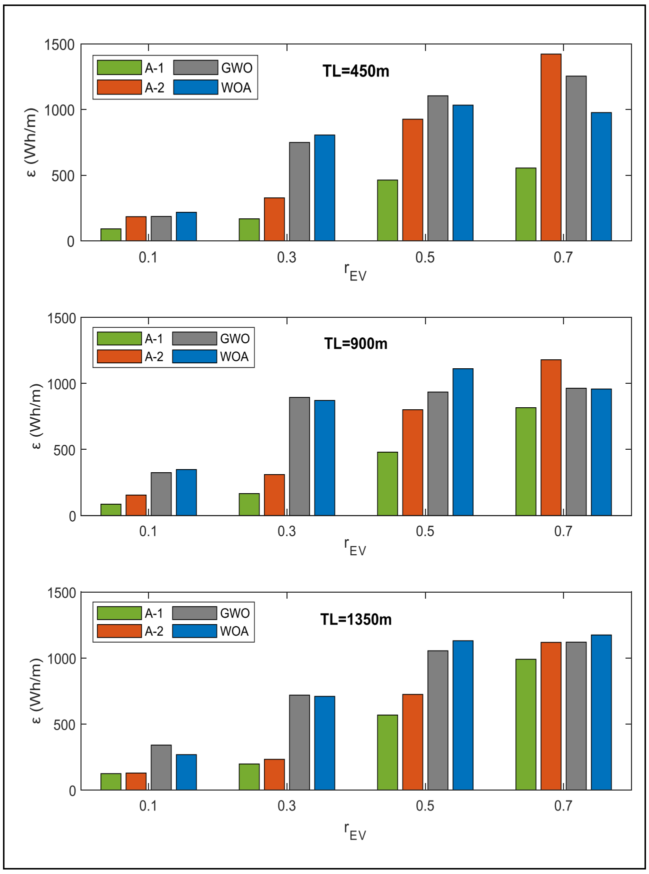

Figure 3. Efficiency of strategies for different $maxTL$ and r_{EV}.

Group B strategies perform better in most cases, as shown in Figure 5. Especially at r_{EV}=0.3, Group A strategies have significantly lower ε than Group B. For example, in Figure 5, the ε of A-2 for $r_{EV} = 0.3$ in $maxTL = 450\ m$ is about 44% of GWO and 40% of WOA. The ε of A-1 is even lower. Group B also suggests more suitable layout plans than Group A at r_{EV}= 0.3. Shifting the r_{EV} rate to higher values is causing a positive difference in most of the ε ratios of the strategies. These differences are not significant for Group A when shifting r_{EV} from 0.1 to 0.3, but shifting r_{EV} 0.3 to 0.5 significantly increases ε. The averages of difference values for all $maxTL$s are 326 Wh/m and 527 Wh/m for A-1 and A-2, respectively. On the other hand, shifting the r_{EV} from 0.1 to 0.3, these averages are around 76 and 134 Wh/m for A-1 and A-2, respectively. Shifting the r_{EV} from 0.1 to 0.3 affects the ε ratios of Group B strategies more positively than Group A. The average ε increase is around 503 Wh/m and 517 Wh/m for GWO and WAO, respectively. However, when shifting r_{EV} from 0.3 to 0.5, the positive difference in ε increase is limited. In addition, there are negative differences in the WOE ε ratios in the shifting r_{EV} from

0.5 to 0.7. A-2 shows an interesting performance at the case for $maxTL = 450$ and $r_{EV} = 0.7$ in Figure 5. The A-2 offers an efficiency of 1423 Wh/m for this case, and this value is the highest among all cases. Also, the A-2 becomes more competitive as its r_{EV} rate increases. As the r_{EV} increases, the efficiency of A-2 increases steadily without fluctuations. A-2 is significantly successful at $r_{EV} = 0.7$ for all $maxTLs$. For $r_{EV} = 0.7$, A-2 proposes best layout plans for $maxTL = 450$ and 900 m than other strategies. For $maxTL = 1350\,m$ only, the efficiency of A-2 is almost equal to GWO, and about 56 Wh/m lower than WOA. WAO has higher efficiency than GWO in 8 of 12 cases. However, in contrast to the GWO, the WAO efficiency does not always increase with the increase in the r_{EV}.

Interestingly, the WOA efficiency decreases as r_{EV} increases from 0.5 to 0.7. The highest decrease is around 14% at $maxTL = 900$, and the lowest is around 4% at $maxTL$=1350. Increasing the length of $maxTL$ from 450 m to 900 m positively affects Group B efficiency for r_{EV} 0.1 and 0.3. For example, the GWO efficiency increases from 186.4 Wh/m to 324.3 Wh/m for r_{EV}= 0.1. The WAO efficiency increases from 218 to 347.9 Wh/m for the same conditions. For r_{EV}= 0.3, GWO and WOA increase by about 20% and 8%, respectively. Group B is generally better than Group A, thus comparing the layout plans proposed by the Group B strategies, and examining the similarities, provides insight into developing a WCT layout plan. Table 1 is proposed to understand the strategies' tendency to distribute WCT sizes by intersections and directions. By categorizing the r_{EV} as low (0.1 and 0.3) and high category (0.5 and 0.9) in Table 1, the trends of WCT deployment strategies became observable. The values in Table 1 are obtained by arithmetic operations of the P and S sets proposed by GWO and WAO. The arithmetic operation sequence is as follows: (1) For r_{EV} (0.1 and 0.3) and (0.5 and 0.7), distribute the GWO and WOA suggested WCT positions directionally, and designate "r_{EV} = low" and "r_{EV} = high", respectively. (2) Assign the average value of the WCT sizes GWO and WAO suggested for each case to the corresponding table cell. (3) Determine the total sizes of the intersections by summing all the cell values in the respective Eastbound (EB) and Westbound (WB) columns. Grand totals, in the bottom row of Table 1, show that algorithms prefer Intersection 1 and Intersection 3 at most to position large size WCTs, i.e. GWO and WOA tend to prefer the intersections located at the entrance/ exits of the corridor.

The last column of Table 1 contains the standard deviation values for each table row. These values provide information about the uniformity of the WCT size distribution. For $maxTL =$ 450 m and 1350 m, the standard deviations for the higher category are lower than for the lower category. This is different at only 900 m. The increase in r_{EV} causes algorithms to distribute WCT sizes more uniformly. In addition, with increasing $maxTL$, the standard deviation values decrease significantly, except for $maxTL = 900\,m$ and higher category. This decrease indicates that algorithms tend to distribute WCT sizes to intersections more uniformly with the increase of $maxTL$. Another interesting result is that with the increasing r_{EV} and values, the algorithms suggest more uniform position and size plans.

This conclusion is supported by the reduction of standard deviations. However, there is a different situation at 900 m and higher category. The disadvantage of heuristic algorithms approaching local optimum can lead to such results. In further studies, such a problem can be overcome by considering the trend of the standard deviation values and re-evaluating such contrary results.

7 Discussion

As stated in the literature review, DWC-S offers a powerful solution to the size-constrained battery problem of electric vehicles. However, the high installation costs of such systems requires careful consideration of the WCT layout plans. In the literature, it is stated that placing DWC-S in signalized intersection corridors can increase charging performance due to low traffic speed. However, a robust method or strategy for deploying a WCT for these regions has not been presented yet. In this study, various strategies were proposed and compared to contribute to the development of robust strategies. The current study found that the layouts proposed by GWO and WOA are more efficient than Group B strategies in most cases. Especially in cases where r_{EV} is low, this advantage is clearer. The reason for this result can be explained by the fact that Group A consists of static strategies and that cannot adapt to the lane usage behavior of BEVs. It appears that this adaptation becomes even more important in low r_{EV} rates. The difference between the two groups becomes smaller as the r_{EV} increases. In other words, as the number of BEVs in the system increases, the efficiency of the floor plans proposed by Group A increases proportionally more than that of Group B. An increase in the r_{EV} ratio of 0.7 leads to a significant increase in the efficiency of Group, especially strategy A-2. As a consequence, A-2 is a highly competitive WCT positioning and sizing strategy at high r_{EV} rates.

The performance of strategy A-2 at $r_{EV} = 0.7$ was surprising. This result can be explained by the fact that a vehicle tends to enter the shortest queue when it approaches a signaled intersection. Thus, the queue lengths in the lanes become approximate when there is a sufficient number of vehicles. BEVs are also showing the same behavior. Thus, the BEV flow is evenly distributed across the lanes and the performance of the A-2 strategy becomes significant, especially at high r_{EV}. Another conclusion is that Group B strategies propose A-2-like layouts as the $maxTL$ increase. Therefore, it will be possible to talk about a threshold value in $maxTL$ for each corridor system.

Table 1. Average WCT dimensions suggested by Group B strategies for intersection directions.

$maxTL$ (m)	Category of r_{EV}	Intersection 1		Intersection 2		Intersection 3		Standard Deviation
		EB	WB	EB	WB	EB	WB	
450	Low	47.65	101.15	22.3	34.65	134.2	71.55	38.95
	High	117.7	75.4	38.55	64.2	35.55	105.95	30.77
900	Low	160.75	116.2	105.2	175.15	205.65	117.1	36.53
	High	246.05	110.45	157.75	175.2	100.2	84.2	55.04
1350	Low	227.05	232.75	232.7	167.1	251.45	208.05	26.78
	High	206.2	224.75	192.95	233.7	211.5	251.25	19.06
∑		1866.1		1599.45		1776.65		

Exceeding this threshold, the optimizations are likely to produce results similar to the A-2. This threshold study was not performed in this study, but determining this threshold in future studies may be useful in reducing optimization process times. This study provided an opportunity to compare the performance of GWO and WOA on the PSP problem. It is the fact that in most situations they produce similar results. Despite the same parameters, however, the WOA efficiency fluctuates more than the GWO. Although GWO turns out to be a more robust algorithm for PSP, this result should be interpreted with caution due to the limited number of analyzes.

The results of the WCT placement plan proposed by the Group B strategies contain key intuitive lessons: The proposal of longer WCTs for the entrance intersections (intersections 1 and 3) of the corridor. This result is quite reasonable considering that the corridor is controlled by a semi-actuated signaling system. Since the arrival intervals of the vehicles at the entrance to the corridor are random, they are in the form of a platoon inside the corridor. Adjusting the constraints based on this result before the optimization process will reduce the search space of the problem and contribute to more efficient results in acceptable processing times.

8 Conclusion

This study aimed to suggest and compare various strategies for the WCT PSP in an intersection corridor. Another aim was to test the performance of state-of-art algorithms. This study has shown that the GWO and WOA algorithms perform significantly better than the pre-determined strategies considered when the ratio of BEVs in the traffic flow is low. However, at high r_{EV}, equally allocating the total WCT length to all road lanes from the stop line is a potential solution strategy. The results of this research also support the idea of placing longer WCT at intersections at corridor entrances. The current findings add to a growing body of literature on increasing the performances of dynamic wireless battery charging stations. Although the study has successfully demonstrated the advantages of the strategies, it has certain limitations in terms of vehicle modes. Since heavy vehicles are not included in the simulations, the analysis results should be interpreted carefully for corridors with a high rate of heavy vehicles in the traffic flow. In addition, it will be useful to repeat these analyzes in further studies for intersections with different geometries and/or managed by different signal control systems. As a result, in this study, the critical effect of positioning and sizing strategies on the efficiency of a DWC-S plant was exposed, and different aspects of this effect were also discussed.

9 Author contribution statements

All contents of this study were carried out with the contribution of Erdem DOĞAN.

10 Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee.

There is no conflict of interest with any person / institution in the article prepared" for the article prepared.

11 References

[1] Etacheri V, Marom R, Elazari R, Salitra, G Aurbach D. “Challenges in the development of advanced Li-ion batteries: a review”. *Energy & Environmental Science*, 4(9), 3243-3262, 2011.

[2] Zheng Y, Dong ZY, Xu Y, Meng K, Zhao JH, Qiu J. “Electric vehicle battery charging/swap stations in distribution systems: comparison study and optimal planning”. *IEEE transactions on Power Systems*, 29(1), 221-229, 2013.

[3] Mohamed AAS, Lashway CR, Mohammed O. “Modeling and feasibility analysis of quasi-dynamic WPT system for EV applications*”. IEEE Transactions on Transportation Electrification*, 3(2), 343-353, 2017.

[4] International EA. *Global EV Outlook 2020: Entering the Decade of Electric Drive?.* Paris, France, OECD Publishing, 2020.

[5] Jang YJ, Ko YD, Jeong S. “Optimal design of the wireless charging electric vehicle”. *IEEE International Electric Vehicle Conference*, Greenville, United States, 4-8 March 2012.

[6] Esser A. “Contactless charging and communication for electric vehicles*”. IEEE Industry Applications Magazine*, 1(6), 4-11, 1995.

[7] Elghanam EA, Hassan MS, Osman AH. “Deployment optimization of dynamic wireless electric vehicle charging systems: a review”. *IEEE International IOT, Electronics and Mechatronics Conference*, Vancouver, Canada, 9-12 September 2020.

[8] Mohrehkesh S, Nadeem T. “Toward a wireless charging for battery electric vehicles at traffic intersections”. *14th international IEEE conference on intelligent transportation systems*, Washington DC, USA, 05-07 October 2011.

[9] Jang YJ, S Jeong, Lee MS. “Initial energy logistics cost analysis for stationary, quasi-dynamic, and dynamic wireless charging public transportation systems”. *Energies,* 9(7), 2016, 483-509.

[10] Deflorio F, Guglielmi P, Pinna I, Castello L, Marfull S. “Modeling and analysis of wireless ‘Charge While Driving’ operations for fully electric vehicles”. *Transportation Research Procedia*, 5, 161-174, 2015.

[11] Li S, Mi CC. “Wireless Power transfer for electric vehicle applications”. *IEEE Journal of Emerging and Selected Topics in Power Electronics*, 3(1), 4-17, 2015.

[12] Zhang J, Tang TQ, Yan Y, Qu X. “Eco-driving control for connected and automated electric vehicles at signalized intersections with wireless charging”. *Applied Energy*, 282(A), 1-8, 2021.

[13] Liu Q, Hu S, Angeloudis P. “Simulation and evaluation of CAVs behavior in an isolated signalized intersection equipped with dynamic wireless power transfer system”. *IEEE Intelligent Transportation Systems Conference*, Auckland, New Zealand, 27-30 October 2019.

[14] Li M, Wu X, Zhang Z, Yu G, Wang Y, MA W. “A wireless charging facilities deployment problem considering optimal traffic delay and energy consumption on signalized arterial”. *IEEE Transactions on Intelligent Transportation Systems*, 20(12), 4427-4438, 2019.

[15] Chen Z, Liu W, Yin Y. “Deployment of stationary and dynamic charging infrastructure for electric vehicles along traffic corridors”. *Transportation Research Part C: Emerging Technologies*, 77, 185-206, 2017.

[16] Fuller M. "Wireless charging in California: Range, recharge, and vehicle electrification". *Transportation Research Part C: Emerging Technologies*, 67, 343-356, 2016.

[17] Zou Y, Liu H, Long J. "Optimizing the location of multi-type charging facilities considering heterogeneous travelers". *System Engineering Theory and Practice*, 40(11), 2946-2957, 2020.

[18] Mubarak M, Üster H, Abdelghany K, Khodayar M. "Strategic network design and analysis for in-motion wireless charging of electric vehicles". *Transportation Research Part E: Logistics and Transportation Review*, 145, 1-21, 2021.

[19] He F, Yin Y, Zhou J. "Deploying public charging stations for electric vehicles on urban road networks". *Transportation Research Part C: Emerging Technologies*, 60, 227-240, 2015.

[20] Liu H, Wang DZW. "Locating multiple types of charging facilities for battery electric vehicles". *Transportation Research Part B: Methodological*, 103, 30-55, 2017.

[21] He J, Yang H, Tang TQ, Huang H-J. "An optimal charging station location model with the consideration of electric vehicle's driving range". *Transportation Research Part C: Emerging Technologies*, 86, 641-654, 2018.

[22] Jawad S, Liu J. "Electrical Vehicle Charging Services Planning and Operation with Interdependent Power Networks and Transportation Networks: A Review of the Current Scenario and Future Trends". *Energies*, 13(13), 3371, 2020.

[23] Jang YJ. "Survey of the operation and system study on wireless charging electric vehicle systems". *Transportation Research Part C: Emerging Technologies*, 95, 844-866, 2018.

[24] Erfani R, Marefat F, Sodagar AM, Mohseni P. "Transcutaneous capacitive wireless power transfer (C-WPT) for biomedical implants". *IEEE International Symposium on Circuits and Systems (ISCAS)*, Baltimore, Maryland, USA, 28-31 May 201.

[25] National Academy of Engineering. *Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2017 Symposium*. Washington, DC, USA, The National Academies Press, 2018.

[26] Suh NP, Cho DH, Rim CT. *Design of on-Line Electric Vehicle (OLEV)*. Editors: Bernard A. Global Product Development. 3-8, France, Springer, 2011.

[27] Mirjalili S, Mirjalili SM, Lewis A. "Grey wolf optimizer". *Advances in Engineering Software*, 69, 46-61, 2014.

[28] Mirjalili S, Lewis A. "The whale optimization algorithm". *Advances in Engineering Software*, 95, 51-67, 2016.

[29] Jiang W, Zhen Y. "A real-time EV charging scheduling for parking lots with PV system and energy store system". *IEEE Access*, 7, 86184-86193, 2019.

[30] Pal A, Bhattacharya A, Chakraborty AK. "Allocation of EV fast charging station with V2G facility in distribution network". *8th International Conference on Power Systems*, Jaipur, Rajasthan, India, December 20-22, 2019.

[31] Shukla A, Verma K, Kumar R. "Multi-objective synergistic planning of EV fast-charging stations in the distribution system coupled with the transportation network". *IET Generation, Transmission & Distribution*, 13(15), 3421-3432, 2019.

[32] Watkins WA, Schevill WE. "Aerial observation of feeding behavior in four baleen whales: Eubalaena glacialis, Balaenoptera borealis, Megaptera novaeangliae, and Balaenoptera physalus". *Journal of Mammalogy*, 60(1), 155-163, 1979.

[33] McShane WR, Roess RP, Prassas ES, *Traffic Engineering*, 3rd ed. New York, USA, Prentice Hall, 1998.

[34] Çakıcı Z, Murat YS, AYDIN MM. "Design of an efficient vehicle-actuated signal control logic for signalized intersections". *Scientia Iranica*, 29(3), 1059-1076, 2021.

[35] Rosu SG, Khalilian M, Cirimele V, Guglielmi P. "A dynamic wireless charging system for electric vehicles based on DC/AC converters with SiC MOSFET-IGBT switches and resonant gate-drive". *42nd Annual Conference of the IEEE Industrial Electronics Society*, Florence, Italy, 23-26 October 2016.