Data Science and Engineering (DSE) Record, Volume 6, Issue 1

Comparison of Minimum Waiting Time and Priority Satisfaction Method with Traditional Method in Electric Vehicle Battery Swapping Scheduling

Nisara Wongutai[1] and Natthanan Promsuk[2]

[1] Master's Degree Program in Data Science, Chiang Mai University, Chiang Mai, Thailand
[2] Department of Computer Engineering, Faculty of Engineering, Chiang Mai University
nisara_w@cmu.ac.th

Abstract. Environmental pollution, particularly from greenhouse gas emissions, has emerged as one of the most pressing global challenges, with the transportation sector being a major contributor. Electric Vehicles (EVs) are increasingly promoted as a sustainable solution to mitigate these emissions; however, their adoption is hindered by one critical limitation—the long charging time, which ranges from several hours for conventional chargers to around 30 minutes for fast chargers. To address this limitation, the concept of an EV Battery Swapping Service (BSS) has been introduced, enabling rapid battery replacement within minutes. The mobility of Battery Swapping Vans (BSVs) further enhances flexibility by overcoming the geographic constraints of fixed charging stations. This study proposes a Battery Swapping Service Request Scheduling (BSSRS) model utilizing the Minimum Waiting Time and Priority Satisfaction (MWT-PS) strategy. Using a simulation dataset of 20 service points with one BSV traveling at a constant speed of 40 km/h to service 19 EVs, the results demonstrate that the MWT-PS algorithm significantly improves service efficiency. Compared to traditional scheduling methods, the MWT-PS reduced the total Euclidean distance to 544.79 kilometers and shortened the overall service duration to 13.62 hours, outperforming both First-Come First-Serve (FCFS) and Highest Credit First (HCF) algorithms. These findings highlight the potential of the proposed scheduling approach to enhance EV adoption by making energy replenishment faster, more efficient, and more sustainable.

Keywords: Electric Vehicle (EV); Battery Swapping Service (BSS); Battery Swapping Van (BSV); Scheduling; Minimum Waiting Time and Priority Satisfaction (MWT-PS)

1. Introduction

Environmental pollution has become a critical global concern, with greenhouse gas (GHG) emissions identified as one of the most significant contributors to climate change. The transportation sector alone accounted for approximately 16.2% of total GHG emissions in 2016, ranking third globally after the energy and industrial sectors [1]. To mitigate this impact, governments around the world, including Thailand, have introduced policies and incentives to accelerate the adoption of Electric Vehicles (EVs). Compared to internal combustion engine (ICE) vehicles, EVs offer a cleaner and more sustainable mode of transportation. However, a major challenge that continues to hinder widespread adoption lies in the extended charging time required to replenish EV batteries [2].

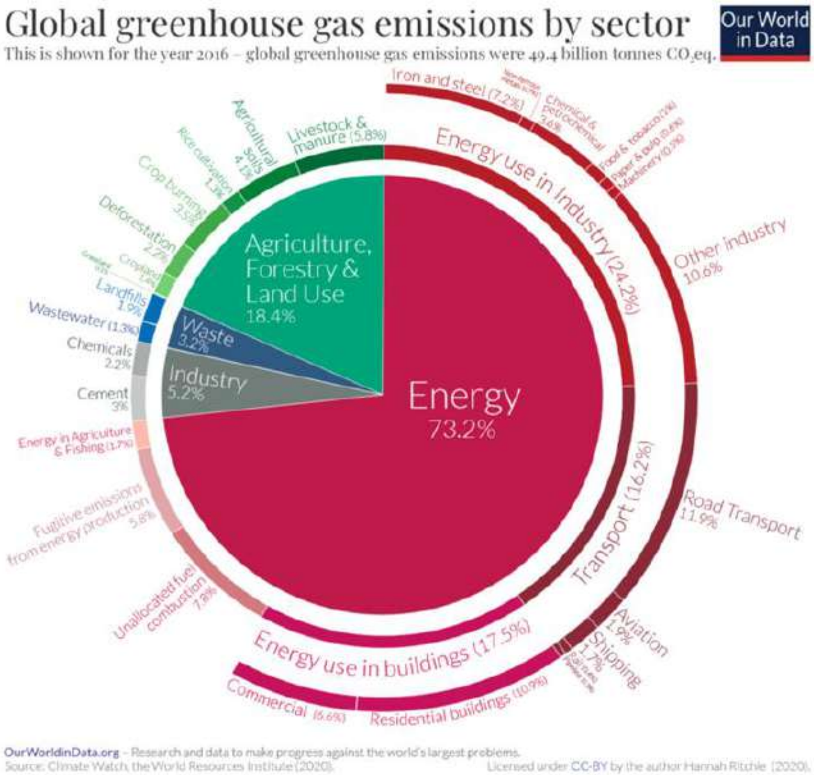

Figure 1 Global Greenhouse Gas Emissions by Sector for 2016
Source: Climate Watch, the World Resources Institute (2020)

Conventional charging methods are categorized into three levels: Level 1 (slow charging), which may take up to 20 hours for a full charge; Level 2 (accelerated charging), which typically requires 4–8 hours; and Level 3 (fast charging), which can reduce charging time to around 30 minutes [3]. Although fast chargers provide a partial solution, they remain insufficient for addressing user convenience on a large scale. This limitation has created demand for alternative solutions that can deliver energy to EVs more rapidly and efficiently.

The Battery Swapping Service (BSS) has emerged as a promising alternative. Instead of waiting for a battery to charge, EV users can replace a depleted battery with a fully charged one within minutes, reducing downtime dramatically [4]. Furthermore, the introduction of Battery Swapping Vans (BSVs) enhances mobility by eliminating the fixed-location constraint of traditional charging or swapping stations [5]. These mobile units allow battery replacements to be conducted flexibly, anytime and anywhere, thereby addressing range anxiety and improving the practicality of EV use.

To maximize the efficiency of such services, effective scheduling strategies are essential. Traditional scheduling approaches such as First-Come First-Serve (FCFS) and Highest Credit First (HCF) provide basic allocation methods but fail to balance user urgency, fairness, and operational efficiency in dynamic environments [6]. Recognizing this gap, this study introduces a Battery Swapping Service Request Scheduling (BSSRS) model based on the Minimum Waiting Time and Priority Satisfaction (MWT-PS) strategy [7]. The proposed model aims to minimize both total service time and travel distance while ensuring priority is given to the most urgent requests.

The primary contribution of this research is the development and evaluation of a scheduling framework that significantly outperforms traditional methods. Through simulation experiments, this study demonstrates the effectiveness of the MWT-PS strategy in reducing service duration and travel distance, thereby enhancing the overall efficiency of EV battery swapping services. Ultimately, the findings seek to support the wider adoption of EVs by addressing one of their most pressing challenges—convenient and sustainable energy replenishment.

2. Literature Review

The increasing adoption of Electric Vehicles (EVs) has motivated researchers to explore alternative energy replenishment methods to overcome the limitations of conventional charging. One such solution is the Battery Swapping Service (BSS), which enables users to replace depleted batteries with fully charged ones in a matter of minutes, offering significant advantages in terms of convenience and efficiency compared to traditional charging [1].

2.1 Previous Studies on EV Battery Swapping and Scheduling

Zhang and Wang [2] proposed an optimization framework for the dispatch of EV batteries between Battery Charging Stations (BCSs) and Battery Swapping Stations (BSSs). Their study applied a K-means clustering algorithm to partition locations in order to reduce travel distances and improve the overall efficiency of dispatch. While this approach demonstrated improvements in battery allocation and logistics, it primarily addressed fixed-location systems, limiting its applicability to mobile scenarios.

Guo and Qiu [3] introduced a mobile battery swapping service utilizing a Battery Swapping Van (BSV) to enhance flexibility and accessibility. They proposed the Minimum Waiting Time and Priority Satisfaction (MWT-PS) scheduling strategy, which prioritizes requests based on urgency and satisfaction metrics. Their findings indicated that the MWT-PS strategy effectively reduces waiting times and improves user satisfaction. However, the study did not fully address the optimization of service routes or scalability when multiple requests occur in real-time.

Table 1. Summarization of Literature review

Related works	Author	Resulting
Optimal Dispatch of Electric Vehicle Batteries between Battery Swapping Stations and Charging Stations	Zhang, X., & Wang, G. (2016)	To use K-means clustering algorithm is utilized to pre-partition the battery charging stations (BCS) and battery swapping stations (BSS) to make the battery dispatch more efficient and effective.
A mobile battery swapping service for electric vehicles based on a battery swapping van	Guo, S., & Qiu, X. (2017)	To provide the battery swapping service efficiently and effectively, the battery swapping service request scheduling is based on minimum waiting time based on priority and satisfaction scheduling strategy (MWT-PS)
Analysis of fast charging and battery swap station based on battery safety.	Li, G., Zhao, G., & Kuang, N. (2022)	-To provide average time to change EV battery swap station based on battery safety, it is around 3 minutes.

2.2 Gaps in Existing Research

Although traditional scheduling methods such as First-Come First-Serve (FCFS) and Highest Credit First (HCF) are widely applied, they fail to balance fairness, urgency, and efficiency in dynamic environments [4]. These methods often result in longer service times and higher travel distances, making them unsuitable for large-scale deployment. In addition, most studies have focused on fixed stations, leaving the problem of mobile BSV scheduling underexplored.

2.3 Objective

Building on prior research, this study addresses these gaps by applying the MWT-PS strategy within the context of a Battery Swapping Service Request Scheduling (BSSRS) model. The approach aims to minimize travel distance, reduce waiting time, and optimize overall service time while prioritizing urgent requests. By doing so, this research seeks to advance the operational efficiency of mobile battery swapping services and provide practical insights for sustainable EV adoption.

3. Data and Methodology

3.1 Research framework

This study is designed to optimize the scheduling process for Electric Vehicle (EV) Battery Swapping Services (BSS) delivered through Battery Swapping Vans (BSVs). The framework integrates a scheduling model, namely the Battery Swapping Service Request Scheduling (BSSRS), which is enhanced by the Minimum Waiting Time and Priority Satisfaction (MWT-PS) strategy. The goal is to minimize the total service time and distance traveled, thereby improving efficiency and user satisfaction.

The overall research process can be summarized as follows:

1. Collect service request data (time, SOC, position, direction).
2. Apply MWT-PS filtering to prioritize urgent requests.
3. Validate sequence order based on priority constraints.
4. Compare results against baseline algorithms (FCFS, HCF).

This structured approach ensures that both efficiency (distance and time) and fairness (priority satisfaction) are achieved in the scheduling process, as illustrated in Figure 1 Research Framework.

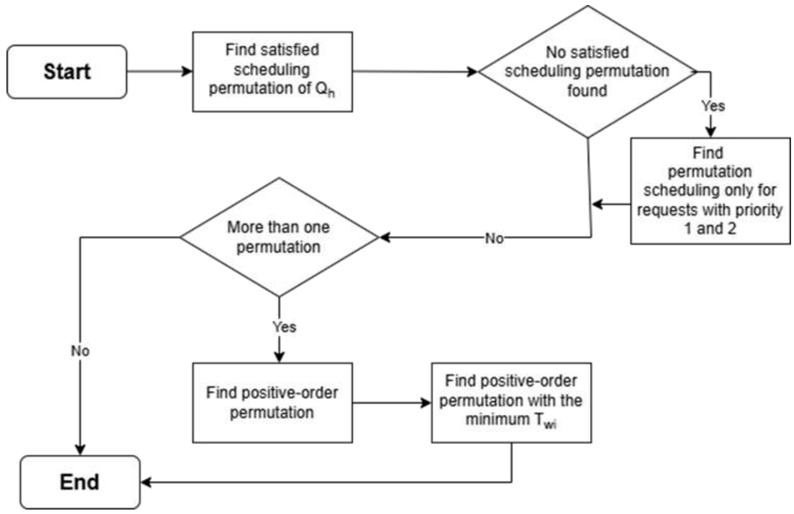

Figure 2 Research Framework

3.2 Framework Overview

In the first stage, Initial Data Filtering, all service requests are screened according to their priority levels and waiting times. The system specifically selects requests that indicate high urgency, such as those with a low State of Charge (SOC), and where the ratio between waiting time and service time is favorable. This step ensures that only the most critical and suitable requests are considered for the scheduling process.

The second stage, Search for Optimal Arrangement, focuses on generating and evaluating possible service routes. The system explores multiple candidate arrangements to determine the most effective schedule. If no feasible arrangement is found at this level, the model narrows its focus to high-priority requests, particularly those ranked 1 and 2, thereby ensuring that urgent cases are guaranteed timely service.

In the third stage, Positive-Order Validation, once a valid scheduling arrangement has been identified, the system confirms the order of service and finalizes the proposed route. During this process, requests that are not selected are systematically deferred and queued for future scheduling rounds, thus maintaining fairness and continuity of service.

Finally, the fourth stage, Post-Validation Management, serves as a follow-up to confirm and implement the finalized schedule. The validated route and order of service are executed, while all non-selected requests remain in the system, awaiting rescheduling in subsequent cycles. This stage ensures that the process is sustainable, adaptive, and capable of handling continuous incoming requests.

3.3 Dataset

To evaluate the scheduling framework, a simulation dataset was constructed to mimic realistic operating conditions. The dataset included twenty service points, consisting of one Battery Swapping Van (BSV) and nineteen Electric Vehicles (EVs) awaiting service. The BSV was modeled to travel at a constant speed of 40 kilometers per hour, providing consistency in calculating travel times between service points.

Each EV was assigned a unique ID, position coordinates, driving direction, and a State of Charge (SOC) level. These attributes were critical in determining service routes and scheduling decisions. SOC thresholds were also introduced to define priority levels, with vehicles at or below 5% SOC classified as the highest priority, ensuring that urgent cases would be addressed first.

This dataset design captured both spatial and operational characteristics of the system, allowing the model to simulate realistic service demand and test the effectiveness of the proposed scheduling method compared to traditional approaches.

Table 2. Dataset

KM1	KM2	SOC
1.685656	49.61798	4
29.92013	85.31436	1
88.74906	70.33533	13
82.11556	26.78606	24
79.65791	97.71551	22
10.76911	96.49005	25
78.25156	87.25005	21
23.47143	5.725055	23
53.26622	64.43047	21
2.11434	53.61698	15
39.46092	70.97986	14
72.95588	67.33938	24
21.04711	20.54152	28
96.85477	89.16348	14
32.97365	17.30287	13
15.14695	55.17925	15
49.60049	66.14591	27
62.51096	31.38789	26
76.11846	82.68622	17
18.80523	91.81921	9

3.4 Evaluation Method

The performance of the proposed Battery Swapping Station Recommendation System (BSSRS) model was evaluated by comparing it with two benchmark scheduling strategies: the First-Come First-Serve (FCFS) method and the Highest Credit First (HCF) method. These two approaches were selected as baselines because they represent traditional scheduling principles commonly applied in service management.

The evaluation focused on two primary performance metrics. The first was the total Euclidean distance traveled by the Battery Swapping Van (BSV), measured in kilometers, which directly reflected travel efficiency and route optimization. The second was the total service time required to complete all requests, measured in hours, which captured the overall responsiveness and timeliness of the scheduling strategy.

By analyzing these metrics, the study aimed to assess not only the operational efficiency of the BSSRS model but also its ability to provide a balanced improvement in both travel distance reduction and service time optimization compared to conventional scheduling approaches.

4. Result and Discussion

This study presents the development and evaluation of the Battery Swapping Service Request Scheduling (BSSRS) model using the Minimum Waiting Time and Priority Satisfaction (MWT-PS) strategy. Compared with First-Come First-Serve (FCFS) and Highest Credit First (HCF), the proposed model demonstrates superior performance in reducing service time, addressing request priority, and improving user satisfaction, highlighting its potential to enhance operational efficiency in EV battery swapping services

4.1 Experimental Setup

The evaluation of the proposed Battery Swapping Service Request Scheduling (BSSRS) model with the MWT-PS strategy was conducted using a simulated dataset of 20 service points, including one Battery Swapping Van (BSV) and 19 Electric Vehicles (EVs). The BSV traveled at a constant speed of 40 km/h. Three scheduling algorithms were compared: First-Come First-Serve (FCFS), Highest Credit First (HCF), and the proposed MWT-PS. Performance was measured by two key indicators:

- Total Euclidean Distance traveled (km)
- Total Service Time (hours)

4.2 First-Come First-Serve (FCFS)

Under the First-Come, First-Serve (FCFS) strategy, requests are processed in the order received without considering urgency or battery level. The results show longer service times and lower efficiency, making FCFS suitable only as a baseline for comparison with more advanced scheduling methods.

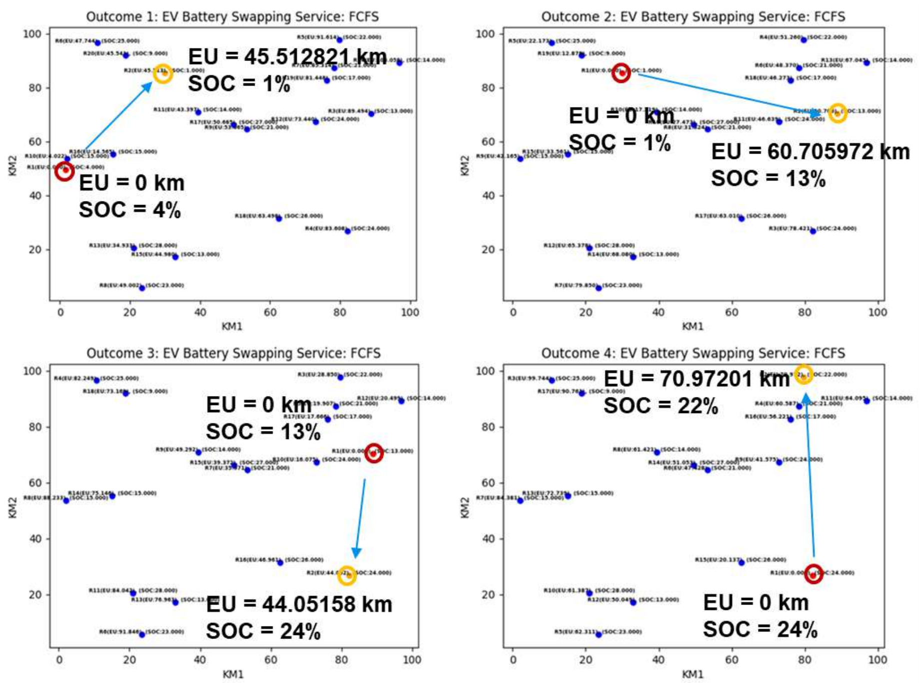

Figure 3 Service Route and SOC Distribution of EV Battery Swapping under FCFS Strategy (Outcome 1 to 4)

Results of the FCFS Strategy (Outcomes 1–4)

The First-Come, First-Served (FCFS) strategy processes battery swapping requests in the exact order in which they are received, without incorporating any consideration of urgency or the State of Charge (SOC) of the vehicles. At each stage of the process, the next service location is determined purely based on the shortest Euclidean distance from the current position of the Battery Swapping Van (BSV).

In Outcome 1, the BSV began at the initial point with coordinates (1.685656, 49.61798) and an SOC of 4%. The first service location selected was at (29.92013, 85.31436), approximately 45.51 kilometers away. Notably, although another vehicle had a critically low SOC of only 1%, the system prioritized distance over urgency, demonstrating a key limitation of this approach.

In Outcome 2, starting from the new position (29.92013, 85.31436), the BSV moved to the next location at (88.74906, 70.33533), a distance of about 60.71 kilometers. The sequence continued to follow the shortest distance principle, disregarding SOC levels of other vehicles in need.

Outcome 3 showed a similar pattern, beginning at (88.74906, 70.33533) and proceeding to (82.11556, 26.78606), which was roughly 44.05 kilometers away. Again, the routing decision was made exclusively on distance, and the process was repeated across the remaining service points.

Finally, in Outcome 4, the BSV started from (82.11556, 26.78606) and selected the next service location at (79.65791, 97.71551), approximately 70.97 kilometers away. The subsequent route selections adhered to the same distance-based logic, illustrating how the FCFS strategy consistently favored spatial proximity over service urgency.

This series of outcomes highlights the fundamental limitation of FCFS in the context of electric vehicle battery swapping: while it ensures a systematic and straightforward routing process, it fails to account for critical urgency factors such as extremely low SOC levels, which may lead to service inefficiencies and reduced user satisfaction.

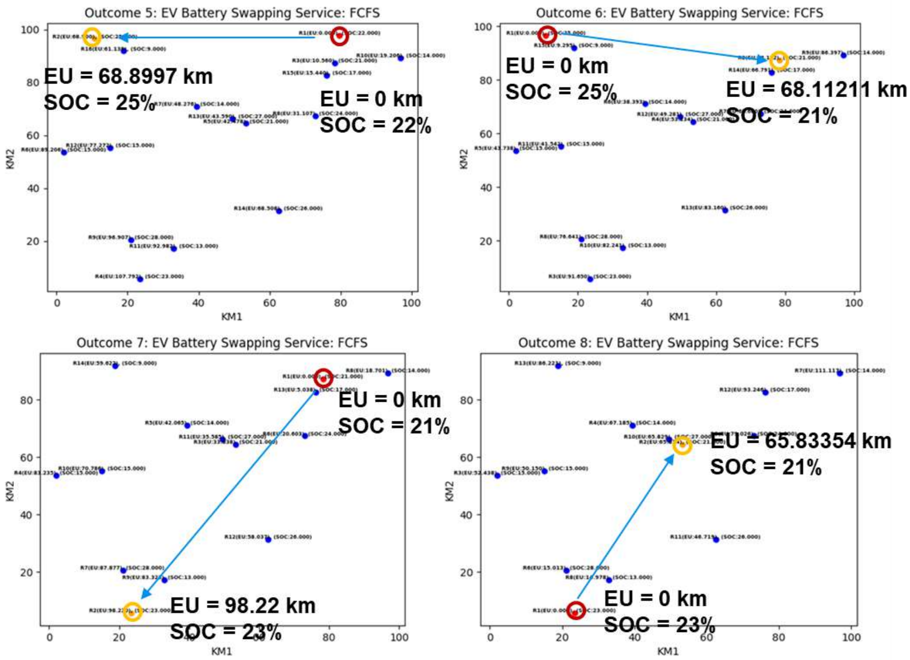

Figure 4 Service Route and SOC Distribution of EV Battery Swapping under FCFS Strategy (Outcome 5 to 8)

Results of the FCFS Strategy (Outcomes 5–8)

In Outcome 5, the BSV started at the coordinates (79.65791, 97.71551) and proceeded to the first service location at (10.76911, 96.49005), which was approximately 68.90 kilometers away. Subsequent service points were similarly selected by following the nearest-distance approach, without consideration of SOC urgency.

In Outcome 6, beginning at (10.76911, 96.49005), the system directed the BSV to the next closest location at (78.25156, 87.25005), covering a distance of about 68.11 kilometers.

The process continued to serve the remaining requests by repeatedly choosing the closest unvisited point, maintaining consistency with the FCFS principle.

For Outcome 7, the BSV started at (78.25156, 87.25005) and selected (23.47143, 5.725055) as the next destination, a significantly larger distance of 98.22 kilometers. Despite the extended travel, the route progression remained governed by the same nearest-neighbor selection rule for subsequent service points.

Finally, in Outcome 8, the starting point shifted to (23.47143, 5.725055), and the BSV moved next to (53.26622, 64.43047), approximately 65.83 kilometers away. The system continued in this manner until all pending requests were completed, strictly adhering to the distance-based logic that characterizes the FCFS strategy.

Overall, Outcomes 5–8 reinforce the observation that while the FCFS method provides a clear and consistent routing mechanism, it does not account for urgency factors such as critically low SOC levels. This results in potential inefficiencies and highlights the need for more adaptive scheduling approaches.

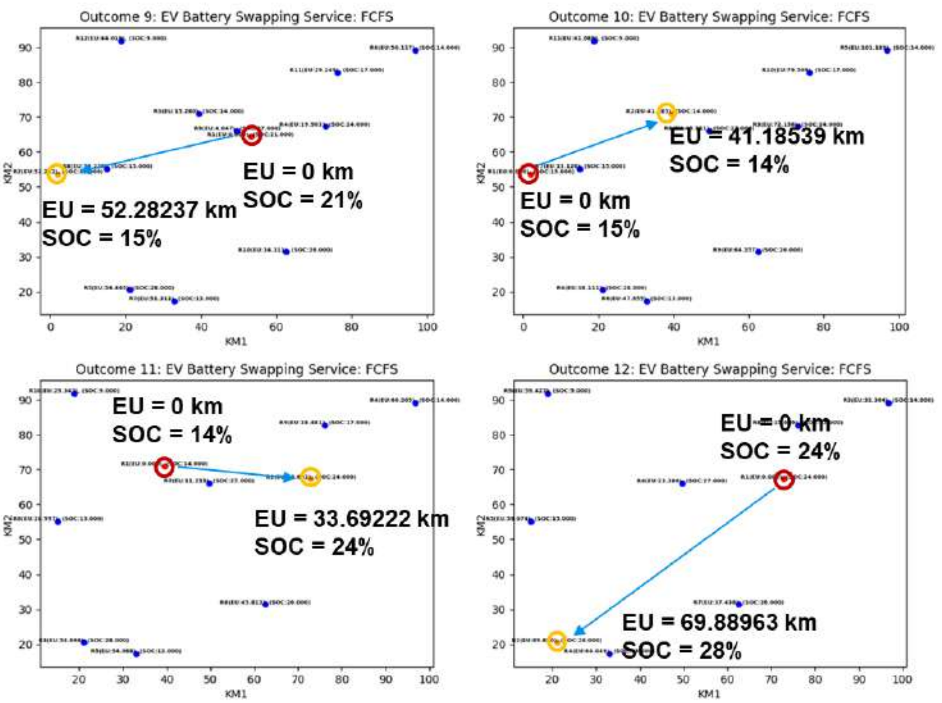

Figure 5 Service Route and SOC Distribution of EV Battery Swapping under FCFS Strategy (Outcome 9 to 12)

Results of the FCFS Strategy (Outcomes 9–12)

In Outcome 9, the BSV began at (53.26622, 64.43047) and traveled to the nearest service location at (2.11434, 53.61698), covering approximately 52.28 kilometers. The route then progressed by selecting the next nearest unvisited point until all requests within this segment were served.

In Outcome 10, starting from (2.11434, 53.61698), the system directed the BSV to (39.46092, 70.97986), a distance of about 41.19 kilometers. The same nearest-distance principle was applied in sequence to complete the subsequent stops.

For Outcome 11, the initial point was (39.46092, 70.97986), from which the BSV proceeded to (72.95588, 67.33938), a relatively shorter distance of 33.69 kilometers. After this step, the vehicle continued its route by consistently selecting the closest remaining service locations until completion.

Finally, in Outcome 12, the BSV started at (72.95588, 67.33938) and selected (21.04711, 20.54152) as the next location, requiring a travel distance of 69.89 kilometers. The process continued in the same manner, repeatedly choosing the nearest unvisited point until all outstanding service requests were fulfilled.

Collectively, Outcomes 9–12 further illustrate how the FCFS strategy ensures systematic coverage of all service points through a nearest-distance rule, but at the cost of neglecting vehicle urgency levels. This highlights the strategy’s efficiency in route determination but also its weakness in addressing critical service priorities.

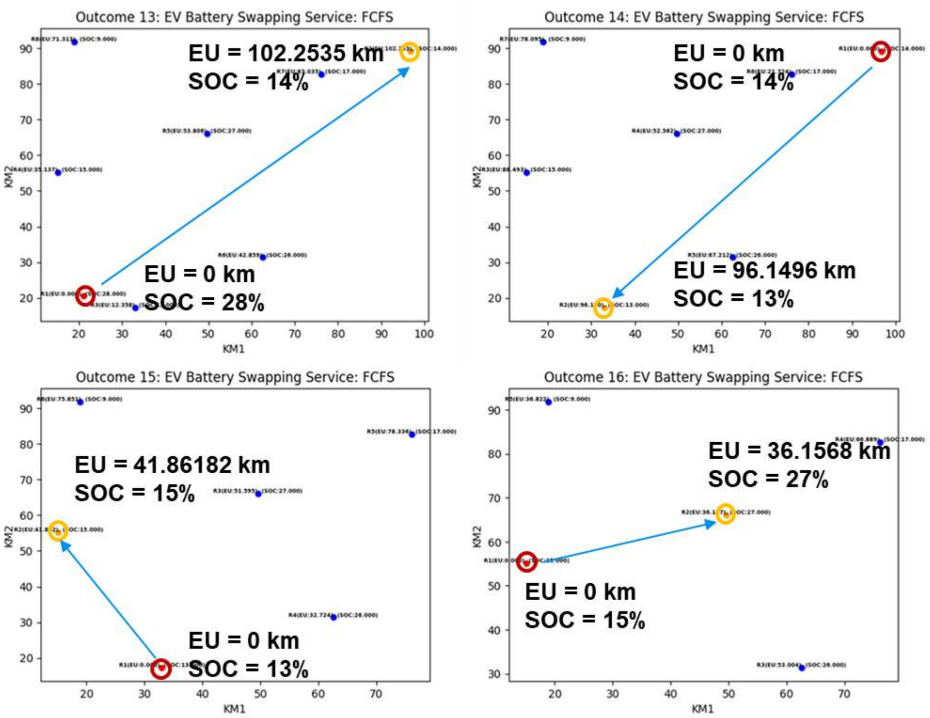

Figure 6 Service Route and SOC Distribution of EV Battery Swapping under FCFS Strategy (Outcome 13 to 16)

Results of the FCFS Strategy (Outcomes 13–16)

In Outcome 13, the Battery Swapping Van (BSV) started at (21.04711, 20.54152) and proceeded to the next service point at (96.85477, 89.16348), covering a distance of approximately 102.25 kilometers. From this point onward, the route was completed by continually choosing the closest unvisited service locations until all were addressed.

In Outcome 14, beginning from (96.85477, 89.16348), the next service location was identified as (32.97365, 17.30287), requiring a travel distance of about 96.15 kilometers. The process continued sequentially, with the BSV following the same distance-based logic to complete the service order.

For Outcome 15, the BSV initiated its route at (32.97365, 17.30287) and selected (15.14695, 55.17925) as the first destination, which was approximately 41.86 kilometers away. After this step, the service route progressed through the remaining locations, consistently applying the nearest-distance selection rule until all requests were fulfilled.

Finally, in Outcome 16, the starting point shifted to (15.14695, 55.17925), and the next service location chosen was (49.60049, 66.14591), a distance of about 36.16 kilometers. The process continued in the same manner, with the BSV systematically visiting the nearest unvisited points until all service demands were completed.

Together, Outcomes 13–16 illustrate the systematic but rigid nature of the FCFS strategy. While the approach ensures that every service location is eventually reached through a logical distance-minimization process, it does so without regard to urgency factors, thereby limiting its effectiveness in scenarios where prioritization is essential.

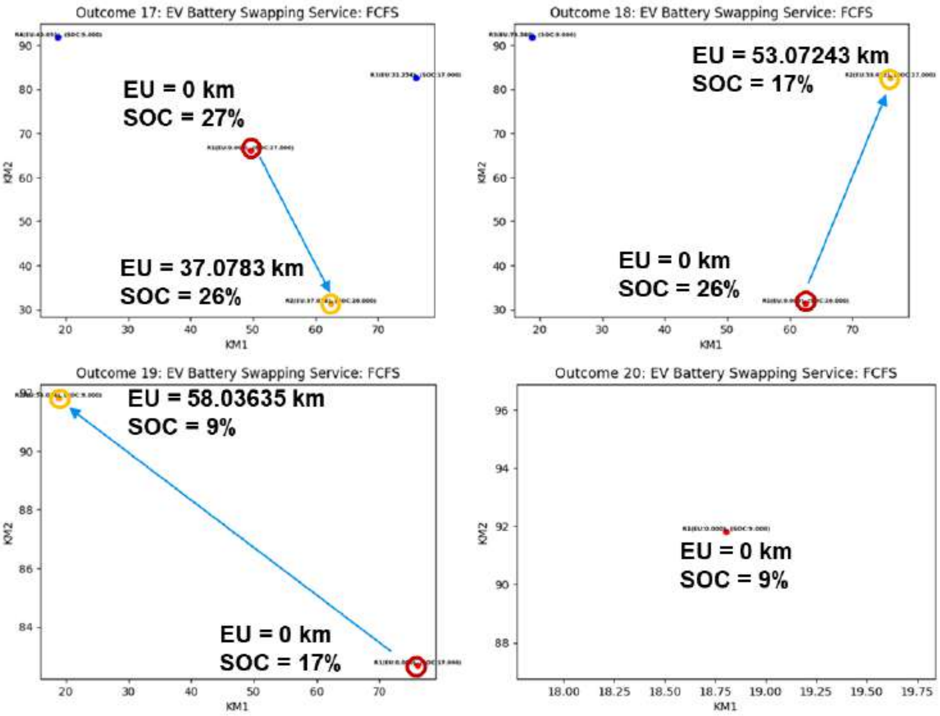

Figure 7 Service Route and SOC Distribution of EV Battery Swapping under FCFS Strategy (Outcome 17 to 20)

Results of the FCFS Strategy (Outcomes 17–20)

The First-Come, First-Served (FCFS) strategy continues to process service requests sequentially, with the next service location determined solely by the shortest Euclidean distance from the current position of the Battery Swapping Van (BSV).

In Outcome 17, the BSV started at (49.60049, 66.14591) and proceeded to (62.51096, 31.38789), a distance of 37.08 kilometers. From there, the remaining service points were visited in order of nearest distance until completion.

In Outcome 18, beginning at (62.51096, 31.38789), the BSV moved to (76.11846, 82.68622), approximately 53.07 kilometers away. The route then progressed to the final service location, applying the same nearest-distance principle.

Outcome 19 involved only two points: starting from (76.11846, 82.68622), the BSV traveled to (18.80523, 91.81921), which was 58.04 kilometers away. As there was only one unvisited location left, the service was completed in a single step.

Finally, in Outcome 20, the BSV began at (18.80523, 91.81921) with an SOC of 9%. Since no additional service requests remained, the operation concluded immediately, with a total Euclidean distance of 0 kilometers.

The cumulative results across Outcomes 1–20 reveal that the FCFS strategy produced a total travel distance of 1,143.97 kilometers and required a service duration of 28.60 hours, based on the assumption of a constant travel speed of 40 km/h.

The evaluation of Outcomes 1–20 demonstrates that the FCFS strategy offers a straightforward and fair mechanism for processing requests, as it treats all vehicles equally without discrimination. However, the results also highlight significant inefficiencies. With a total travel distance of 1,143.97 kilometers and 28.60 hours of service time, the FCFS method proved to be considerably less efficient than alternative approaches such as Highest Credit First (HCF) and Minimum Waiting Time with Priority and Satisfaction (MWT-PS).

A critical limitation of the FCFS approach is its failure to incorporate urgency factors such as low State of Charge (SOC). In several cases, vehicles with critically low SOC levels experienced delays in service because the scheduling mechanism prioritized distance rather than urgency. This shortcoming underscores the inadequacy of FCFS in optimizing operational performance for battery swapping services. While useful as a baseline method for comparison, FCFS ultimately reinforces the importance of adopting more advanced strategies—such as HCF and MWT-PS—that balance efficiency with fairness while ensuring timely service for critical requests.

4.3 Highest Credit First (HCF)

Under the Highest Credit First (HCF) strategy, requests from EVs with the lowest state of charge are prioritized to address urgent needs. While this approach reduces waiting times for critical cases, the results indicate higher travel distances and longer service durations compared to the proposed model, making HCF less efficient overall.

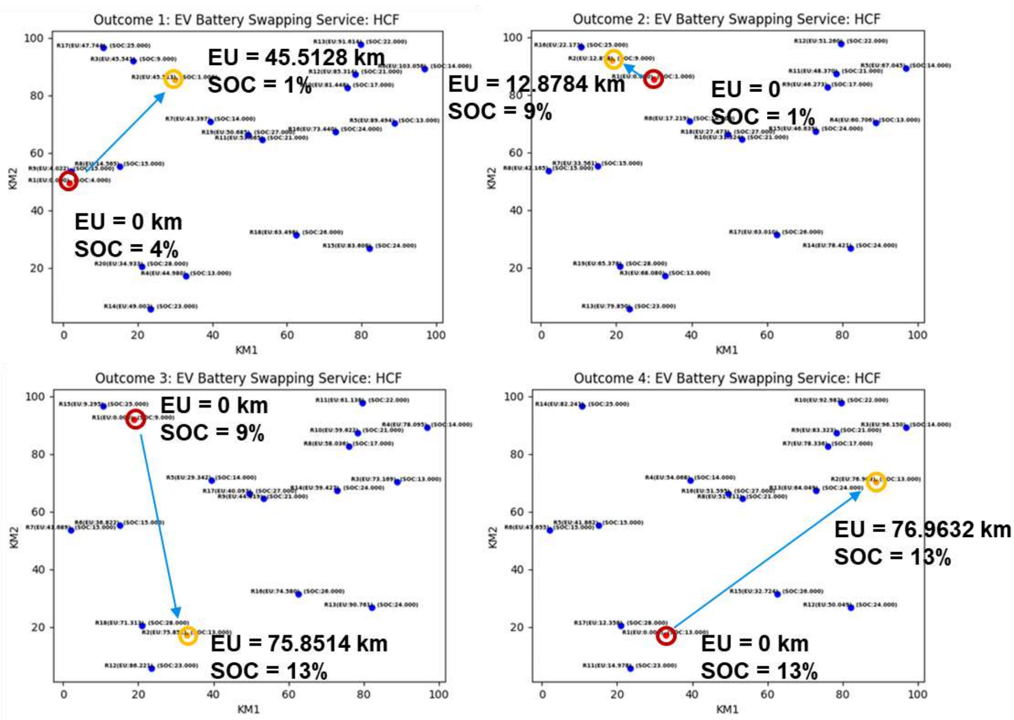

Figure 8 Service Route and SOC Distribution of EV Battery Swapping under HCF Strategy (Outcome 1 to 4)

Results of the HCF Strategy (Outcomes 1–4)

The Highest Credit First (HCF) strategy prioritizes service for electric vehicles (EVs) with the lowest State of Charge (SOC), ensuring that those in urgent need of battery replacement are addressed before less critical requests. Unlike the First-Come, First-Served (FCFS) approach, which relies solely on distance, HCF integrates urgency as a decisive factor while still considering travel feasibility based on Euclidean distance.

In Outcome 1, the Battery Swapping Van (BSV) started at coordinates (1.68566, 49.618) with an SOC of 4%. The first service location selected was (29.9201, 85.3144), where the EV had an SOC of only 1%, representing the most critical demand. This required a travel distance of approximately 45.51 kilometers. The route then proceeded by balancing low SOC levels with feasible travel distances.

In Outcome 2, beginning at (29.9201, 85.3144) with an SOC of 1%, the next service location chosen was (18.8052, 91.8192), which had an SOC of 9% and was located about 12.88 kilometers away. The sequence continued by weighing urgency against travel considerations, maintaining the HCF principle of prioritizing low SOC levels.

For Outcome 3, the BSV started at (18.8052, 91.8192) with an SOC of 9% and proceeded to (32.9737, 17.3029), where the SOC was relatively low. The distance traveled was approximately 75.85 kilometers. This outcome illustrated how the HCF strategy prioritized vehicles with lower SOC while simultaneously ensuring route feasibility.

In Outcome 4, the BSV began at (32.9737, 17.3029) with an SOC of 13% and selected (88.7491, 70.3353) as the next service location, where the SOC was again relatively low. The required travel distance was about 76.96 kilometers. Subsequent service points were chosen by applying the same HCF logic, balancing the urgency of SOC levels with practical travel efficiency.

Collectively, Outcomes 1–4 demonstrate that the HCF strategy introduces urgency as a critical decision-making parameter, allowing the system to better align service allocation with the immediate needs of vehicles, while still considering the efficiency of travel routes.

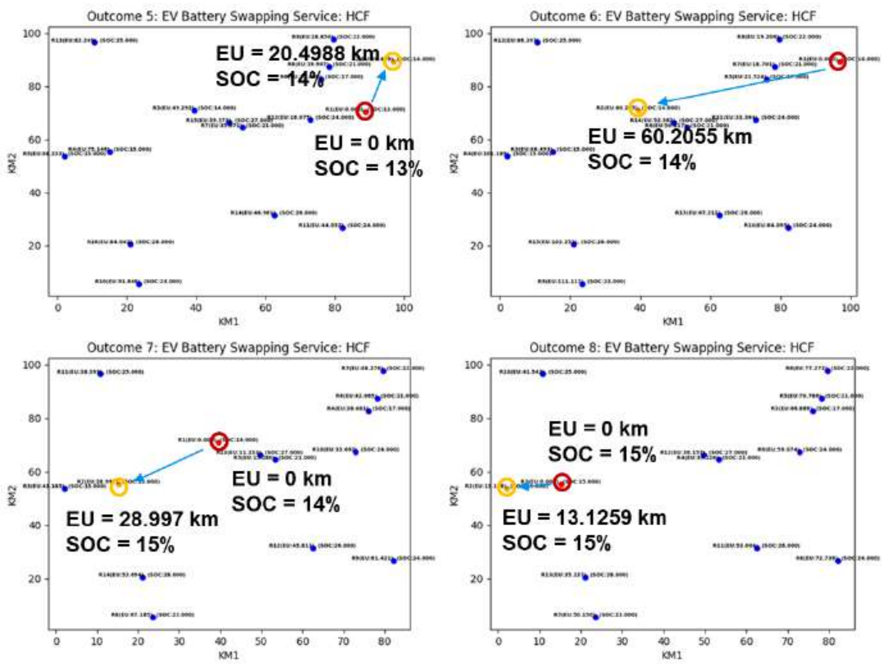

Figure 9 Service Route and SOC Distribution of EV Battery Swapping under HCF Strategy (Outcome 5 to 8)

Results of the HCF Strategy (Outcomes 5–8)

The Highest Credit First (HCF) strategy continues to emphasize prioritizing electric vehicles (EVs) with the lowest State of Charge (SOC) while still considering the feasibility of travel distance when determining the sequence of service. This dual focus ensures that urgent requests are handled first without disregarding operational efficiency.

In Outcome 5, the Battery Swapping Van (BSV) started from (88.7491, 70.3353) with an SOC of 13%. The first service location selected was (96.8548, 89.1635), where the EV had a relatively low SOC. The required travel distance was approximately 20.50 kilometers.

From this point onward, the route progressed by giving precedence to vehicles with lower SOC levels while balancing feasible travel paths.

In Outcome 6, beginning at (96.8548, 89.1635) with an SOC of 14%, the next service location chosen was (39.4609, 70.9799), about 60.21 kilometers away. The system continued to serve the subsequent requests by applying the HCF principle—giving priority to urgency while still considering distance efficiency.

For Outcome 7, the BSV initiated its route at (39.4609, 70.9799) with an SOC of 14% and proceeded to (15.1469, 55.1793), a location with relatively low SOC and situated approximately 28.99 kilometers away. Subsequent service locations were determined using the same logic, combining urgency-based prioritization with practical distance considerations.

Finally, in Outcome 8, the BSV started at (15.1469, 55.1793) with an SOC of 15% and selected (2.1143, 53.6170) as the next service point, which was about 13.13 kilometers away. The remaining requests were then served sequentially by consistently applying the HCF scheduling principle of prioritizing low SOC vehicles alongside feasible travel routes.

Together, Outcomes 5–8 reinforce the effectiveness of the HCF strategy in integrating urgency into the scheduling process. By combining SOC prioritization with distance-based feasibility, the approach ensures that critical needs are met promptly while avoiding unnecessary inefficiencies in travel.

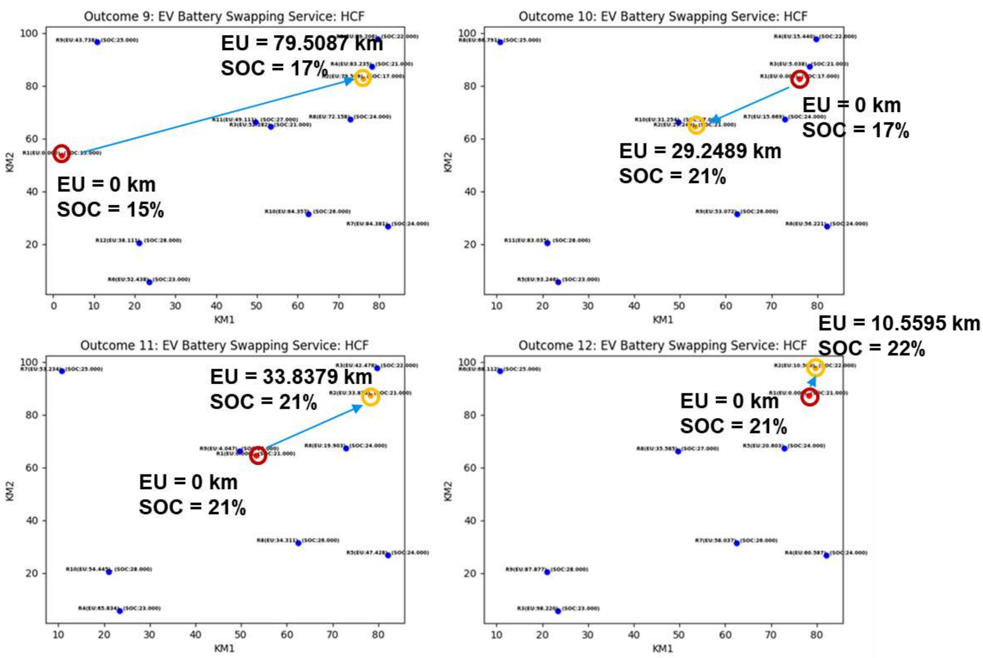

Figure 10 Service Route and SOC Distribution of EV Battery Swapping under HCF Strategy (Outcome 9 to 12)

Results of the HCF Strategy (Outcomes 9–12)

The Highest Credit First (HCF) strategy consistently emphasizes serving electric vehicles (EVs) with the lowest State of Charge (SOC) as the top priority, while simultaneously considering the feasibility of travel distances in planning service routes. This approach ensures that urgent requests are addressed promptly without disregarding operational efficiency.

In Outcome 9, the Battery Swapping Van (BSV) began at (2.11434, 53.6170) with an SOC of 15%. The next service location chosen was (76.1185, 82.6862), where the SOC was relatively low. This required a travel distance of approximately 79.51 kilometers. The route then continued with priority given to critical SOC levels, balanced against feasible travel paths.

In Outcome 10, starting from (76.1185, 82.6862) with an SOC of 17%, the BSV moved to (53.2662, 64.4305), approximately 29.25 kilometers away, to serve an EV with relatively low SOC. The sequence progressed in accordance with the HCF principle, which integrates urgency with efficient routing.

For Outcome 11, the BSV initiated service at (53.2662, 64.4305) with an SOC of 21% and proceeded to (78.2516, 87.2501), located about 33.84 kilometers away. The system continued to apply the urgency-first selection rule, ensuring that vehicles with lower SOC were prioritized in the service order.

Finally, in Outcome 12, the BSV started from (78.2516, 87.2501) with an SOC of 21% and selected (79.6579, 97.7155) as the next service location, requiring only 10.56 kilometers of travel. The remaining requests were fulfilled by consistently applying the HCF scheduling principle, combining SOC urgency with practical travel efficiency.

Collectively, Outcomes 9–12 further demonstrate the ability of the HCF strategy to balance urgency-based prioritization with feasible routing. This dual consideration improves responsiveness to vehicles in critical need, while still maintaining reasonable levels of travel efficiency.

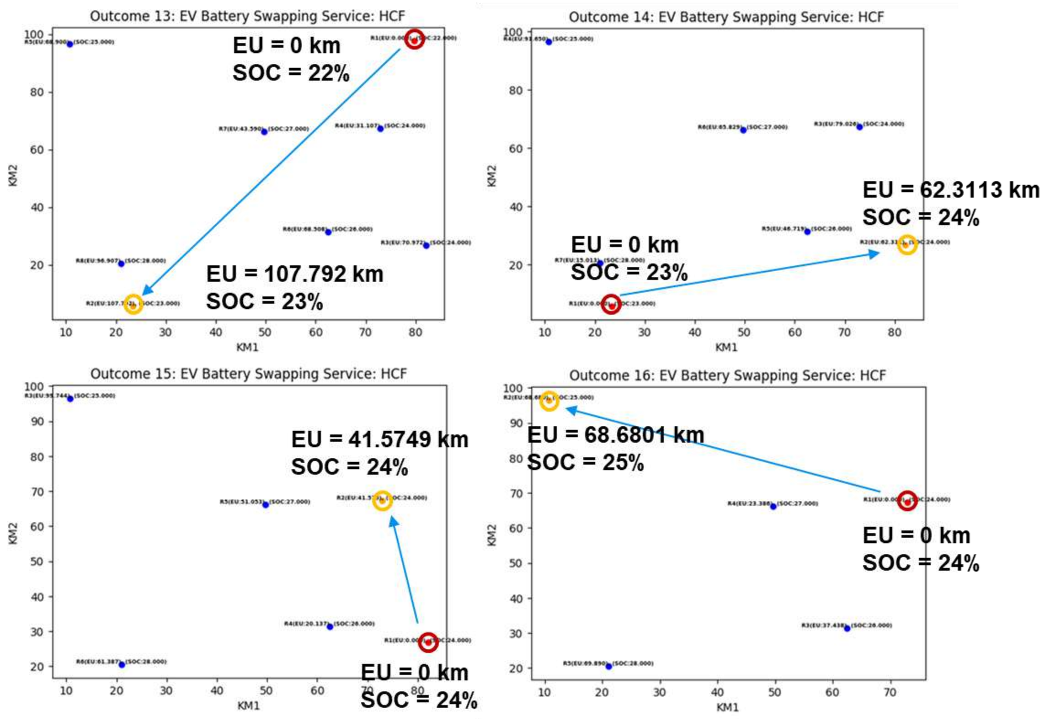

Figure 11 Service Route and SOC Distribution of EV Battery Swapping under HCF Strategy (Outcome 13 to 16)

Results of the HCF Strategy (Outcomes 13–16)

The Highest Credit First (HCF) strategy maintains its focus on prioritizing electric vehicles (EVs) with lower State of Charge (SOC) levels while simultaneously accounting for travel feasibility in route selection. This dual consideration enables the system to address urgent needs without compromising operational efficiency.

In Outcome 13, the Battery Swapping Van (BSV) began at (79.6579, 97.7155) with an SOC of 22%. The first service location was (23.4714, 5.7251), which required a travel distance of approximately 107.79 kilometers. The route then progressed by consistently prioritizing vehicles with lower SOC levels while balancing the travel path.

In Outcome 14, starting from (23.4714, 5.7251) with an SOC of 23%, the BSV proceeded to (82.1156, 26.7861), approximately 62.31 kilometers away. The remaining service requests were completed according to the HCF principle, ensuring that vehicles with lower SOC were addressed first.

For Outcome 15, the BSV started at (82.1156, 26.7861) with an SOC of 24% and moved to (72.9559, 67.3394), about 41.57 kilometers away. The route continued by applying the HCF logic, giving priority to lower SOC vehicles while maintaining efficient travel.

Finally, in Outcome 16, the BSV began at (72.9559, 67.3394) with an SOC of 24% and traveled to (10.7691, 96.4900), a distance of approximately 68.68 kilometers. From this point onward, the system served the remaining requests by applying the same urgency-first scheduling principle while considering feasible routes.

Together, Outcomes 13–16 reaffirm the strength of the HCF strategy in balancing urgency and efficiency. By consistently prioritizing EVs with lower SOC while also accounting for travel distance, the strategy demonstrates its ability to deliver more responsive and practical scheduling compared to purely distance-based approaches.

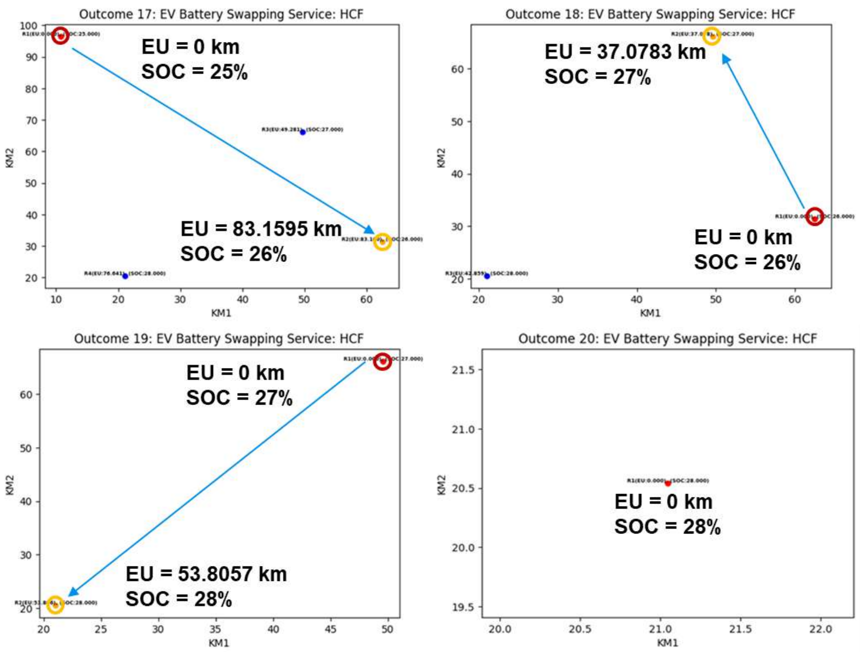

Figure 12 Service Route and SOC Distribution of EV Battery Swapping under HCF Strategy (Outcome 17 to 20)

Results of the HCF Strategy (Outcomes 17–20)

The Highest Credit First (HCF) strategy continues to prioritize vehicles with lower State of Charge (SOC) values; however, in later stages, most remaining vehicles exhibited relatively higher SOC levels.

In Outcome 17, the Battery Swapping Van (BSV) began at (10.7691, 96.4900) with an SOC of 25%. The first service location selected was (62.5110, 31.3879), approximately 83.16 kilometers away. From this point, the route continued by giving priority to vehicles with lower SOC while still considering travel efficiency.

In Outcome 18, starting from (62.5110, 31.3879) with an SOC of 26%, the BSV proceeded to (49.6005, 66.1459), located 37.08 kilometers away. The final service location reached was (21.0471, 20.5415), which concluded the sequence, with vehicles at this stage having comparatively higher SOC levels.

For Outcome 19, the BSV started from (49.6005, 66.1459) with an SOC of 27% and traveled to the last unvisited location at (21.0471, 20.5415), approximately 53.81 kilometers away. This outcome represented the near-final stage of service, as only a small number of requests remained.

Finally, in Outcome 20, the BSV started and ended at (21.0471, 20.5415) with an SOC of 28%. As no additional service requests were pending, the Euclidean distance traveled was 0 kilometers, marking the conclusion of the HCF sequence.

The cumulative outcomes reveal that the HCF strategy required a total travel distance of 941.59 kilometers and a service duration of 23.54 hours, assuming a constant BSV speed of 40 km/h. Compared to the First-Come, First-Served (FCFS) approach, which demanded 1,143.97 kilometers and 28.60 hours, HCF achieved a reduction of 202.38 kilometers and 5.06 hours. This demonstrates the strategy's improved efficiency in both distance and time.

The evaluation of Outcomes 1–20 under the HCF strategy highlights its advantages over the FCFS approach. By incorporating SOC urgency into scheduling decisions, HCF not only reduced travel distance and service duration but also improved responsiveness to vehicles in critical need, thereby enhancing user satisfaction. Specifically, the reduction of 202.38 kilometers and 5.06 service hours illustrates the tangible efficiency gains of this method.

However, while more effective than FCFS, HCF does not fully optimize travel routes, as its primary focus remains on SOC prioritization. This sometimes results in longer travel distances when low-SOC vehicles are located far apart. Consequently, although HCF represents a significant improvement in balancing urgency with feasibility, it still falls short of achieving overall route optimization. This limitation underscores the necessity for more advanced strategies such as Minimum Waiting Time with Priority and Satisfaction (MWT-PS), which aim to integrate both efficiency and fairness into the scheduling process.

4.4 MWT-PS (Minimum Waiting Time and Priority Satisfaction)

The Minimum Waiting Time and Priority Satisfaction (MWT-PS) model optimizes scheduling by balancing efficiency and fairness, considering both urgency and waiting time. Results show that MWT-PS achieves shorter service durations and reduced travel distances compared to traditional methods, demonstrating its effectiveness in improving overall scheduling performance.

The system first filters requests with Rank = 1 or 2 and Decision = True (Twi > Tsi). From this subset, the next service point is selected based on feasibility, distance, and priority. In this case, the chosen location is (29.92013, 85.31436).

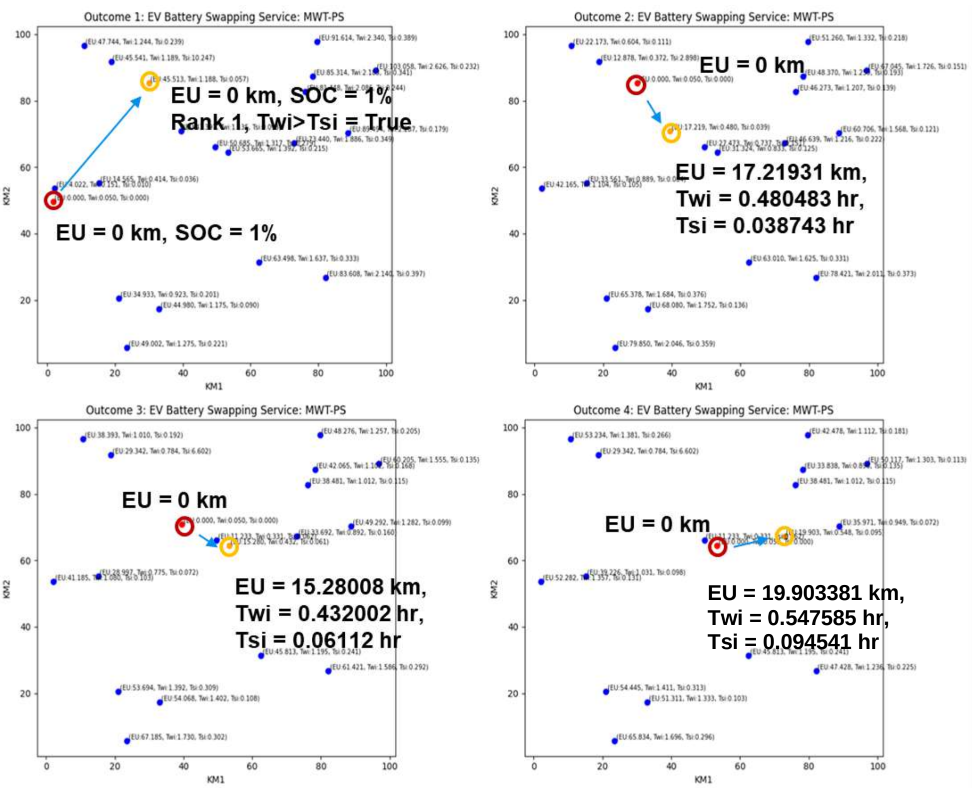

Figure 13 Service Route, Waiting Time, and Individual Serving Time of EV Battery Swapping under MWT-PS Strategy (Outcome 1 to 4)

Results of the MWT-PS Strategy (Outcomes 1–4)

The Minimum Waiting Time – Priority Score (MWT-PS) strategy integrates both priority ranking and waiting time suitability to optimize service sequencing. By applying the decision rule Twi > Tsi and prioritizing requests with Rank = 1 or 2, the system ensures that urgent cases are served promptly while simultaneously minimizing unnecessary travel distances. This dual evaluation enables a more balanced scheduling approach compared to methods that consider only distance or urgency alone.

In Outcome 1, the Battery Swapping Van (BSV) began at (1.6857, 49.6180). The first service location selected was (29.9201, 85.3144), chosen not only for feasibility but also due to its higher priority ranking. Graph annotations of Euclidean distance (EU), waiting time (Twi), and priority score (Tsi) supported the decision-making process, confirming the suitability of the selection.

In Outcome 2, the BSV started from (29.9201, 85.3144) and moved to (39.4609, 70.9799), a distance of approximately 17.22 kilometers. The decision was based on favorable conditions of both priority ranking and waiting time, ensuring efficiency and fairness in service allocation.

For Outcome 3, the BSV began at (39.4609, 70.9799) and selected (53.2662, 64.4305) as the next service location, covering 15.28 kilometers. This choice reflected the optimal balance between high-priority ranking and the shortest feasible waiting time, showcasing the system’s ability to align efficiency with urgency.

Finally, in Outcome 4, the BSV started from (53.2662, 64.4305) and proceeded to (72.9559, 67.3394), approximately 19.90 kilometers away. The location was selected according to priority ranking and optimized waiting time, further reinforcing the MWT-PS strategy’s capacity to deliver both responsiveness and travel efficiency.

Collectively, Outcomes 1–4 demonstrate the effectiveness of the MWT-PS approach in combining urgency-driven scheduling with travel feasibility, ensuring that vehicles with critical needs are served promptly while overall system efficiency is maintained.

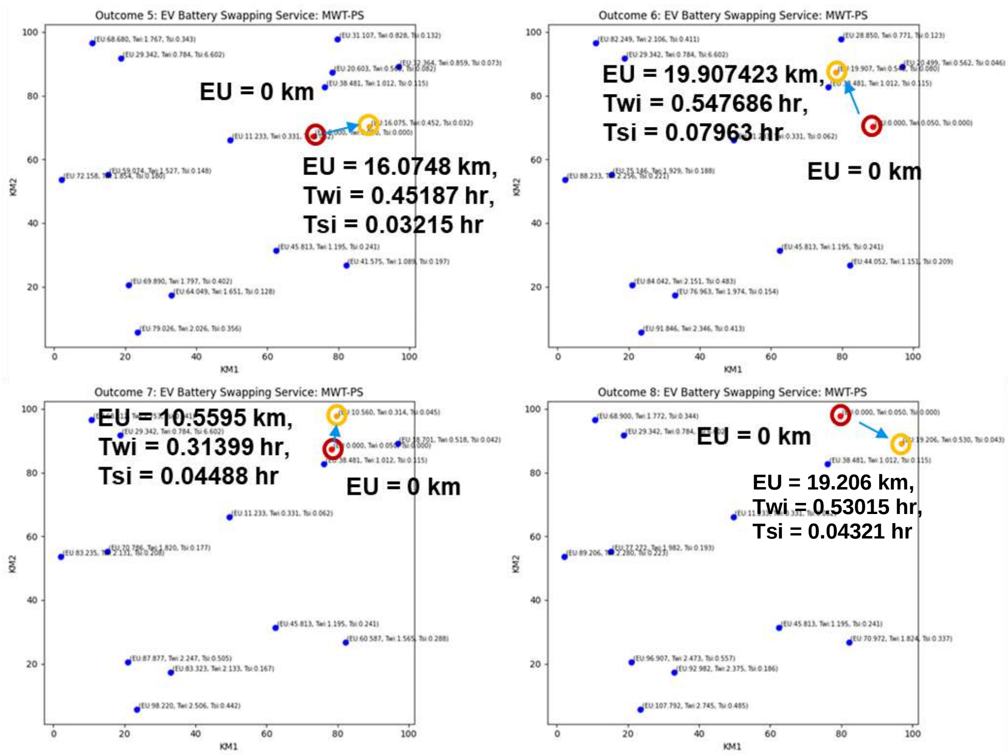

Figure 14 Service Route, Waiting Time, and Individual Serving Time of EV Battery Swapping under MWT-PS Strategy (Outcome 5 to 8)

Results of the MWT-PS Strategy (Outcomes 5–8)

The Minimum Waiting Time – Priority Score (MWT-PS) strategy continues to optimize service routing by evaluating both priority ranking and minimum waiting time, thereby ensuring that the scheduling process remains efficient while also responsive to urgent needs.

In Outcome 5, the Battery Swapping Van (BSV) started at (72.9559, 67.3394) and proceeded to the next service location at (88.7491, 70.3353), approximately 16.07 kilometers away. This decision reflected the strategy's emphasis on minimizing waiting times and improving route efficiency through prompt service allocation.

In Outcome 6, beginning from (88.7491, 70.3353), the BSV selected (78.2516, 87.2501) as the next point, requiring a travel distance of 19.91 kilometers. The choice aligned with the MWT-PS principle of balancing service priority with travel feasibility, thereby reducing potential delays.

For Outcome 7, the BSV initiated its route at (78.2516, 87.2501) and moved to (79.6579, 97.7155), which was only 10.56 kilometers away. This outcome highlighted the effectiveness of MWT-PS in prioritizing urgent requests and minimizing waiting time while maintaining travel efficiency.

Finally, in Outcome 8, starting from (79.6579, 97.7155), the BSV traveled to (96.8548, 89.1635), approximately 19.21 kilometers away. The selection was guided by the dual factors of priority ranking and waiting time optimization, ensuring timely and efficient service delivery.

Collectively, Outcomes 5–8 demonstrate the adaptability of the MWT-PS strategy in balancing urgency with travel feasibility. By consistently selecting routes that minimize waiting times while addressing high-priority requests, the strategy enhances overall system responsiveness and operational performance.

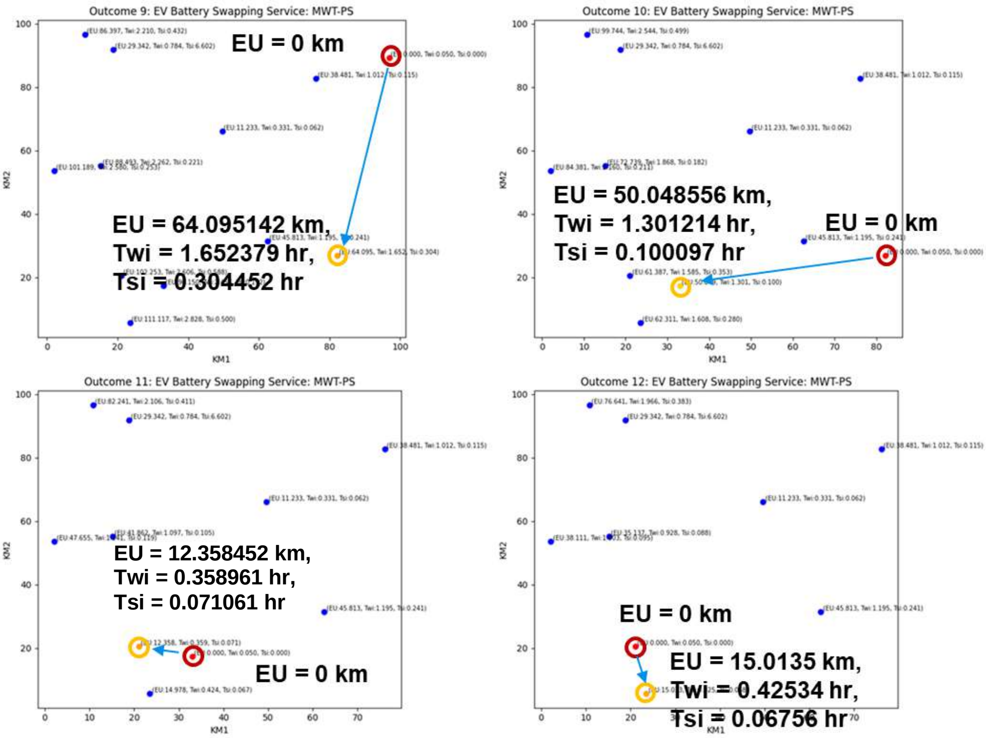

Figure 15 Service Route, Waiting Time, and Individual Serving Time of EV Battery Swapping under MWT-PS Strategy (Outcome 9 to 12)

Results of the MWT-PS Strategy (Outcomes 9–12)

The Minimum Waiting Time – Priority Score (MWT-PS) strategy continues to allocate service efficiently by selecting locations based on priority ranking and waiting time suitability, while also minimizing travel distance wherever possible. This integrated approach enhances both responsiveness to urgent needs and overall operational efficiency.

In Outcome 9, the Battery Swapping Van (BSV) began at (96.8548, 89.1635) and moved to (82.1156, 26.7861), requiring a travel distance of approximately 64.10 kilometers. This decision reflected timely prioritization combined with calculated route efficiency.

In Outcome 10, starting from (82.1156, 26.7861), the BSV proceeded to (32.9737, 17.3029), a distance of 50.05 kilometers. The selection was made through a balanced assessment of priority scores and waiting times, ensuring that urgent service needs were addressed without compromising routing efficiency.

For Outcome 11, the BSV departed from (32.9737, 17.3029) and traveled to (21.0471, 20.5415), approximately 12.36 kilometers away. This represented a prompt and strategic decision consistent with the MWT-PS principle of minimizing service delays while maintaining operational feasibility.

Finally, in Outcome 12, the BSV began at (21.0471, 20.5415) and selected (23.4714, 5.7251) as the next service location, covering a distance of 15.01 kilometers. The decision was made by carefully evaluating both priority ranking and waiting time suitability, ensuring that service delivery was both timely and efficient.

Collectively, Outcomes 9–12 highlight the ability of the MWT-PS strategy to integrate urgency-based prioritization with efficient routing, resulting in faster response to critical requests while maintaining balanced and practical travel paths.

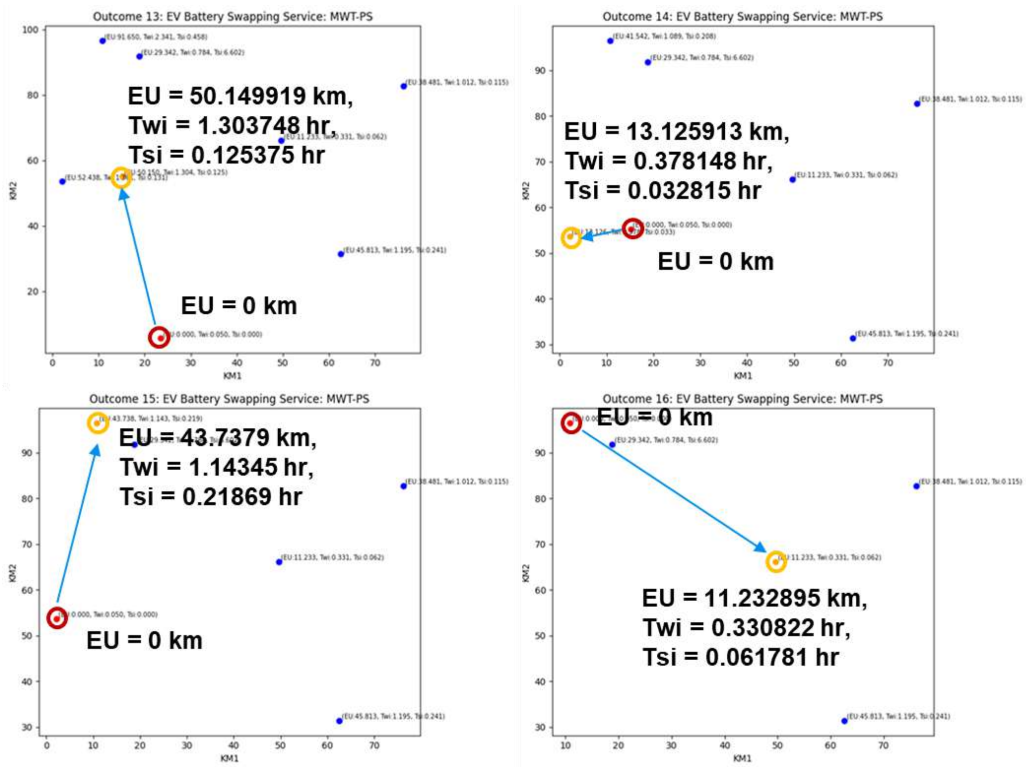

Figure 16 Service Route, Waiting Time, and Individual Serving Time of EV Battery Swapping under MWT-PS Strategy (Outcome 13 to 16)

Results of the MWT-PS Strategy (Outcomes 13–16)

The Minimum Waiting Time – Priority Score (MWT-PS) strategy continues to apply a combined evaluation of priority ranking and waiting time suitability in order to determine service sequences that are both timely and efficient. This dual consideration ensures that urgent needs are met promptly while maintaining optimized travel routes.

In Outcome 13, the Battery Swapping Van (BSV) began at (23.4714, 5.7251) and selected (15.1469, 55.1793) as the next service location, requiring a travel distance of 50.15 kilometers. The decision reflected a data-driven approach that balanced timely service delivery with route optimization.

In Outcome 14, starting from (15.1469, 55.1793), the BSV proceeded to (2.1143, 53.6170), only 13.13 kilometers away. This outcome demonstrated the strategy's ability to make rapid and efficient selections consistent with MWT-PS principles, thereby enhancing overall performance.

For Outcome 15, the BSV departed from (2.1143, 53.6170) and traveled to (10.7691, 96.4900), a distance of 43.74 kilometers. The selection was based on a careful assessment of priority and waiting time, reinforcing the system's capacity to support effective and well-informed scheduling decisions.

Finally, in Outcome 16, the BSV started at (10.7691, 96.4900) and moved to (49.6005, 66.1459), approximately 11.23 kilometers away. This outcome represented a rapid yet optimal decision under the MWT-PS framework, ensuring efficient routing and reliable service delivery.

Collectively, Outcomes 13–16 illustrate how MWT-PS maintains a consistent balance between urgency and efficiency. By integrating priority evaluation with waiting time suitability, the strategy not only ensures timely service for vehicles in need but also sustains operational effectiveness through optimized travel paths.

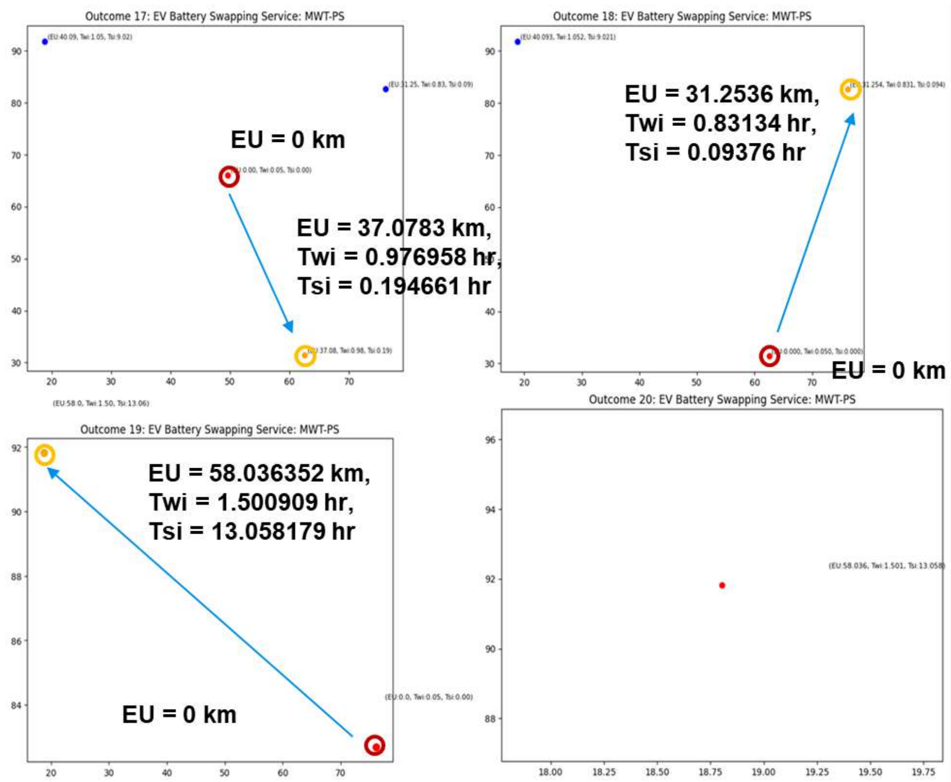

Figure 17 Service Route, Waiting Time, and Individual Serving Time of EV Battery Swapping under MWT-PS Strategy (Outcome 17 to 20)

Results of the MWT-PS Strategy (Outcomes 17–20)

The Minimum Waiting Time – Priority Score (MWT-PS) strategy continues to schedule service by combining priority ranking with waiting time suitability, aiming to achieve both timely responses and efficient routing. However, the results from Outcomes 17–20 also highlight certain limitations of the method, particularly when decision thresholds are not met.

In Outcome 17, the Battery Swapping Van (BSV) started from (49.6005, 66.1459) and proceeded to (62.5110, 31.3879), approximately 37.08 kilometers away. The selection demonstrated efficiency in accordance with MWT-PS criteria, supporting operational continuity and timely allocation.

In Outcome 18, the BSV began at (62.5110, 31.3879) and selected (76.1185, 82.6862) as the next service location, covering 31.25 kilometers. The decision reflected both urgency and minimized waiting time, exemplifying the strategy's effectiveness in balancing service priority with travel feasibility.

For Outcome 19, starting at (76.1185, 82.6862), the next service point was identified as (18.8052, 91.8192), requiring 58.04 kilometers of travel. However, the evaluation produced a decision of FALSE, since the calculated difference between waiting time (Twi) and service time (Tsi) equaled –11.56 hours. This negative outcome indicated that the request was infeasible under MWT-PS conditions, highlighting a critical limitation when timing thresholds are not satisfied.

Finally, in Outcome 20, beginning at (18.8052, 91.8192), no valid next service location was selected. The decision was marked as FALSE due to unmet thresholds in both SOC and waiting time conditions. This scenario illustrates the constraint of the MWT-PS strategy, where requests outside acceptable parameters cannot be served, despite operational continuity requirements.

Collectively, Outcomes 17–20 demonstrate that while the MWT-PS strategy effectively balances urgency and efficiency, it remains vulnerable to feasibility limitations when waiting time and priority thresholds are not aligned. These findings suggest that although MWT-PS significantly improves upon traditional strategies, further refinement may be necessary to address scenarios in which urgent service requests cannot be accommodated under strict rule-based conditions.

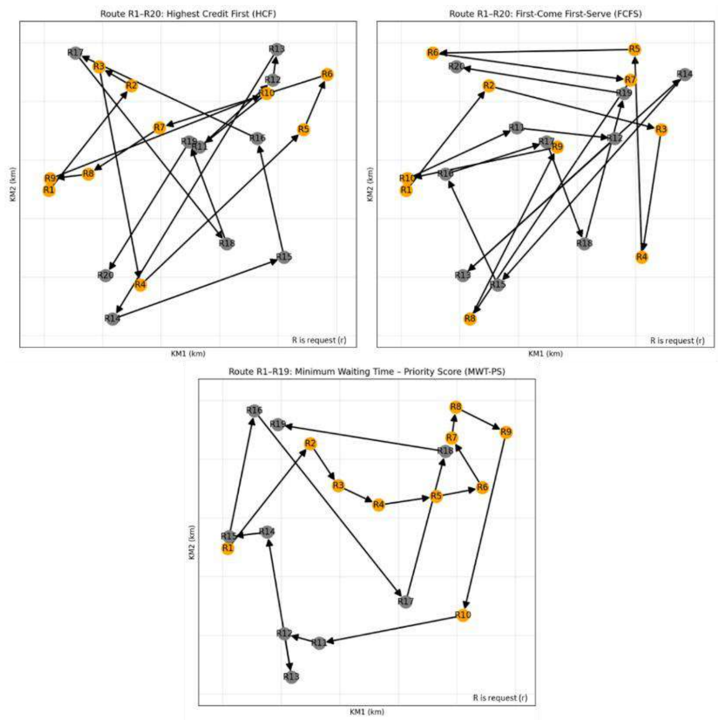

Figure 18 Comparison Spatial Visualization of Service Orderings Generated by Three Strategies on the (KM1, KM2) plane: (top-left) HCF, (top-right) FCFS, and (bottom) MWT-PS

In this study, R denotes the set of service requests, defined as $R = \{R_1, R_2, \ldots, R_n\}$ where each R_i represents the *i-th service request* that must be scheduled and routed in the service process. Figure 4.61 compares the service sequences of FCFS, HCF, and MWT-PS on the (KM1, KM2) plane. FCFS produces many crossings and long hops due to ignoring spatial proximity, leading to the highest travel distance (1143.97 km) and duration (28 h 36 min). HCF reduces waiting times but still causes long detours across zones (941.59 km, 25 h 33 min). MWT-PS achieves the most spatially continuous route, minimizing crossings and backtracking, with the lowest distance (544.79 km) and duration (13 h 36 min).

Summary of Results

The MWT-PS strategy achieved the shortest travel distance (544.79 km) and the fastest service time (13.62 hours), outperforming both FCFS (1,143.97 km, 28.60 hours) and HCF (941.59 km, 23.54 hours). Compared to FCFS, MWT-PS reduced travel distance by 599.18 km and service duration by 14.98 hours. Against HCF, it saved 397.80 km and 9.92 hours. These results highlight MWT-PS as the most efficient and balanced approach, effectively combining waiting time and priority considerations.

Discussion of Findings - MWT-PS

The MWT-PS strategy outperformed both FCFS and HCF by reducing travel to 544.79 km and service time to 13.62 hours. Its strength lies in combining waiting time and priority ranking, ensuring timely service while minimizing redundant travel. Unlike HCF, which ignores real-time waiting constraints, MWT-PS delivers greater efficiency and responsiveness, making it the most practical approach for mobile EV battery swapping.

4.5 Comparative Results

The experimental results are summarized in Table 3.

Table 3. Comparison of Scheduling Algorithms

Algorithm	Total Distance (km)	Total Service Time (hrs)	MWT-PS vs FCFS	MWT-PS vs HCF
FCFS	1,143.97	28.60	52.4%	42.1%
HCF	941.59	23.54	52.4%	42.1%
MWT-PS	544.79	13.62	~15 hours	~12 hours

The results clearly show that the MWT-PS strategy significantly outperforms the baseline approaches. Compared to FCFS, MWT-PS reduced the total travel distance by more than 52% and service time by over 52%. Against HCF, the improvements were 42% in distance and 42% in time. MWT-PS vs FCFS and MWT-PS vs HCF are quantitative indicators are consistent with the visual analysis. The MWT-PS strategy significantly reduces total travel distance and service time by approximately 52.4% compared with FCFS and 42.1% compared with HCF. This demonstrates that MWT-PS achieves the most efficient routing while still maintaining urgency and satisfaction constraints.

5. Summary

This study proposes a Battery Swapping Service Request Scheduling (BSSRS) model for mobile electric vehicle (EV) battery swapping services. The research builds upon prior work by applying the Minimum Waiting Time - Priority and Satisfaction (MWT-PS) strategy, aiming to balance operational efficiency with user satisfaction. Unlike traditional scheduling methods such as First-Come-First-Served (FCFS) and Highest Current First (HCF), the MWT-PS approach explicitly incorporates waiting time reduction, service fairness, and prioritization of urgent requests.

The methodology involves three key steps:

Decision-Based Filtering - Requests are filtered by comparing waiting time (Twi) and service time (Tsi) to ensure efficient service allocation.
Distance Calculation - Euclidean distance is used to determine the proximity between EVs and available Battery Swapping Stations (BSS).
Positive-Order Validation - The final ranking mechanism ensures fairness and logical sequencing of service orders, avoiding inconsistencies in scheduling.

Experiments were conducted using a dataset of 20 swapping points under simulated conditions. The results demonstrate that the MWT-PS model effectively reduces waiting time, improves fairness in service allocation, and achieves higher overall system performance compared to FCFS and HCF.

The study acknowledges its limitations, including reliance on a single dataset and simulated conditions. Future work should focus on improving data realism through Google Maps API integration, expanding datasets for robustness, and incorporating the real-world positions of EVs to better reflect waiting times in diverse scenarios. By addressing these challenges, the research provides practical insights for enhancing mobile EV battery swapping services and contributes to sustainable EV adoption.

6. Discussion

This study proposed a Battery Swapping Service Request Scheduling (BSSRS) model for Electric Vehicle (EV) energy replenishment, integrating the Minimum Waiting Time and Priority Satisfaction (MWT-PS) strategy. The results demonstrated that the proposed approach significantly improves service efficiency compared to traditional scheduling methods. Specifically, the MWT-PS strategy reduced the total travel distance to 544.79 km and the overall service duration to 13.62 hours, outperforming both the First-Come First-Serve (FCFS) and Highest Credit First (HCF) algorithms. These improvements highlight the potential of the model to make EV adoption more practical and sustainable by minimizing waiting time, optimizing travel distance, and prioritizing urgent requests.

The contributions of this research are twofold:

1. Validation of priority-based scheduling - The findings confirm that considering urgency and state of charge (SOC) in scheduling decisions enhances both fairness and operational efficiency in mobile battery swapping services.
2. Demonstration of practical applicability - The study shows that the MWT-PS strategy can effectively balance user satisfaction with operational performance, making it suitable for real-world deployment.

Nevertheless, the study is limited to a single Battery Swapping Van (BSV) operating under simulated conditions. Future research should extend this work by incorporating multi-van coordination, real-time traffic data, and integration with APIs such as Google Maps to estimate dynamic vehicle speeds and actual EV parking locations. Expanding the dataset beyond the current 20 swapping points to multiple sets and averaging the results would also improve the robustness of performance evaluation. Moreover, future model development should explicitly address the waiting time of EVs by considering realistic request scenarios, such as vehicles breaking down on the road, parked at home, or stopped at temporary locations. In addition, integrating renewable energy considerations and economic cost analysis could further strengthen the practical relevance and sustainability of the proposed model.

Ultimately, this research contributes toward accelerating EV adoption by improving the convenience, flexibility, and sustainability of battery swapping services, thereby supporting global efforts to reduce greenhouse gas emissions in the transportation sector.

References

[1] Masindi, V., & Muedi, K. (2018). Environmental Pollution: Overview. IntechOpen.

[2] Jain, A. (1993). Climate change and the enhanced greenhouse effect. Environmental Monitoring and Assessment.

[3] World Resources Institute. (2016). Global greenhouse gas emissions by sector. Climate Watch Data. https://www.climatewatchdata.org/

[4] Hall, D., & Lutsey, N. (2017). Effects of battery electric vehicles on lifecycle emissions. International Council on Clean Transportation (ICCT).

[5] Lu, X., & Zhou, Y. (2013). Design of electric vehicle battery swapping system. In Proceedings of the IEEE International Conference on Transportation Electrification.

[6] Zhang, X., & Wang, G. (2016). Optimal dispatch of electric vehicle batteries between battery swapping stations and charging stations. Journal of Cleaner Production.

[7] Guo, S., & Qiu, X. (2017). A mobile battery swapping service for electric vehicles based on a battery swapping van. Journal of Advanced Transportation.

[8] Ramanathan, U. (2012). Supply chain collaboration for improved forecast accuracy of promotional sales. International Journal of Operations & Production Management, 32(6), 676–695.

[9] Wongutai, N. (2025). EV battery swapping service based on battery swapping van with black hole algorithm [Master's thesis, Chiang Mai University].