

# Verification of Big Data Analysis on Dynamic Wireless Power Transfer for Electric Vehicles Focused on Traffic Signal GPS

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**ABSTRACT:** Dynamic wireless power transfer (DWPT) system primarily consists of transmitter coils embedded in the road to send power and receiver coils installed in electric vehicles (EVs) to receive power. By utilizing the DWPT system, EVs can receive power while driving, which is expected to improve driving range and reduce the battery capacity required. However, studies specifically focus on the potential of DWPT to reduce battery capacity is limited. Previous studies have analyzed the minimum battery capacity required for EVs under the assumption that DWPT is conducted when vehicles are stationary and the brake is applied, with a focus on vehicles operating on general roads. However, this analysis did not consider conditions related to intersections, and it did not ensure that the vehicles were indeed stopped. In this paper, we conduct an analysis using the GPS data of vehicles traveling on general roads in Kashiwa city and traffic signal GPS information. We analyze the ratio of DWPT conducted per drive cycle under the condition that power transfer occurs when a vehicle is within 30 m of a traffic signal, and we compare these results with those of previous study.

**KEY WORDS:** Dynamic wireless power transfer, Electric vehicles, Big data.

## 1. INTRODUCTION

Electric vehicles (EVs) have gained attention as a sustainable mode of transportation that emits no greenhouse gases (GHGs) during operation, contributing to the realization of a more sustainable transport society. However, challenges remain, including the GHG emissions generated during the manufacturing of EVs, and the production of the electricity used for charging, as well as the limitations imposed by the range, which depends on the battery <sup>(1)-(3)</sup>. Equipping EVs with larger batteries to extend the driving range not only increases GHG emissions during battery production but also increases vehicle weight, leading to higher rolling resistance and increased energy consumption during driving.

Dynamic Wireless Power Transmission (DWPT) is a technology that wirelessly transmits power to a running EV <sup>(4)-(9)</sup>. It can extend the cruising range of EVs while minimizing battery weight. DWPT is particularly effective when implemented on highways and near intersections, and it is gaining global attention as a potential solution to address the challenges faced by EVs. Additionally, stationary wireless power transfer, which transfers power to stationary vehicles in parking lots, is also being studied <sup>(10)</sup>. In addition, a method of feeding power using electric fields

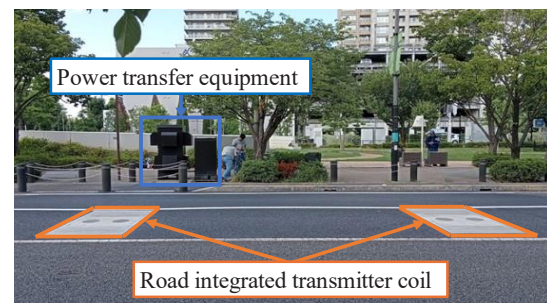


Fig.1. Road utilized for the demonstration of DWPT.

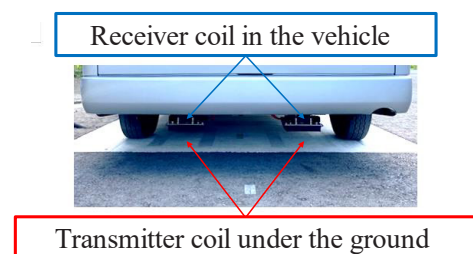


Fig.2. Vehicles utilized for the demonstration of DWPT.

has also been devised <sup>(11)</sup>. Fig. 1 illustrates the structure of vehicles and the DWPT system demonstrated in Kashiwa city. The vehicle in Fig. 2 is equipped with receiver coils that collect power from transmitter coils embedded in the road. With this system, the driver

simply needs to drive on roads equipped with DWPT, and power is continuously supplied to the EV's battery. This reduces not only the amount of battery needed onboard the vehicle but also the GHG emissions associated with battery production. For these reasons, DWPT is expected to become a key technology that addresses the challenges of EVs and promotes their widespread adoption.

While the benefits of DWPT in reducing EV battery weight have been acknowledged, few studies have discussed the minimum required battery capacity for EVs. Previous study conducted in Kashiwa city, estimated the minimum necessary battery capacity under the assumption that DWPT is conducted when the vehicle is stationary <sup>(12)</sup>. However, this analysis was limited to situations where the vehicle is stopped, without utilizing GPS data to confirm whether the stop occurs near an intersection. Other studies have also been conducted on the optimal placement of DWPT systems <sup>(13)</sup>. This study does not assume that the transmitter coils are embedded near traffic signals. This study assumes that the transmitter coils are embedded 30 m in front of the traffic signal.

In this study, we focus on the presence of traffic signals as the defining criterion for proximity to an intersection. Using the GPS data from both traffic signals and vehicles, we conducted an analysis based on the assumption that power transfer through DWPT occurs when the distance between the traffic signal and the vehicle is within 30 m <sup>(14)</sup>. The ratio of power transfer per drive cycle was calculated using both the method employed in this study and previous study. The goal is to verify the accuracy of previous studies.

The structure of this paper is as follows: Chapter 2 provides a detailed explanation of the GPS data for vehicles and traffic signals used in this study. Chapter 3 outlines the conditions under which DWPT is conducted in both previous study and this study. Chapter 4 describes the method used to analyze the ratio of DWPT conducted per drive cycle. Chapter 5 presents the results of the analysis, showing the ratio of power transfer per drive cycle for each method. Finally, Chapter 6 concludes the paper with a summary of the findings.

## 2. DETAILS OF THE DATA USED

In this chapter, we explain the vehicle data and traffic signal GPS information utilized for the analysis.

### 2.1. Vehicle big data

The big data analyzed in this study is based on a data sampled

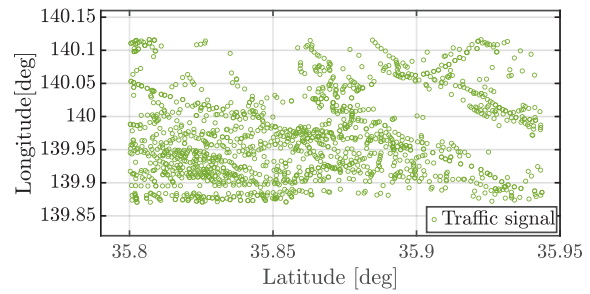


Fig.3. Locations of traffic signal in Kashiwa city.

every 3 seconds for vehicles following a typical drive cycle.

The data set consists of a total of 913 vehicles collected over a three-month period from February 1, 2023, to April 30, 2023. Only vehicles whose vehicle time series data were empty or did not pass through Kashiwa city were excluded from the analysis. Furthermore, the analysis is limited to vehicles traveling on general roads and excludes data from non-road locations such as parking lots, highways, ferry routes, and other roads.

### 2.2. GPS information on traffic signals

The traffic signal GPS data used in this study is restricted to signals within Kashiwa city. Fig. 3 shows the actual GPS coordinates (latitude and longitude) of the traffic signals utilized. The target traffic signals are specified by their latitude and longitude, forming a rectangular boundary around the Kashiwa city area. The latitudes of the upper and lower boundaries are 35.9438132 deg and 35.8002341 deg, respectively. The longitudes of the left and right boundaries are 139.8703181 deg and 140.1162723 deg, respectively. There are a total of 1,605 traffic signals within the region.

## 3. CONDITIONS FOR DWPT OPERATION

This chapter explains the conditions under which DWPT is conducted. The conditions are divided into two categories: those based on previous study and those applied in this study.

### 3.1. Conditions used in previous study (Case 1)

In previous study, the following conditions were considered for DWPT conducted <sup>(12)</sup>:

- The vehicle's speed is 0.
- The brake is applied.
- The vehicle is located on a general road.

DWPT is conducted when the above conditions are met.

In other words, it was assumed that vehicles satisfying these three conditions are mostly located at intersections.

### 3.2. Conditions used in this study (Case 2)

In this study, the following conditions are considered for DWPT conducted:

- The distance between the vehicle and the traffic signal is less than 33.3 m.
- The vehicle is located on a general road.

In this study, DWPT is conducted when these conditions are satisfied. The reasoning behind these conditions is as follows. In previous study, DWPT could be conducted even when the vehicle was stopped outside of an intersection. Because the GPS information of the traffic signal is not considered. Since most traffic signals are located at intersections, the conditions in this study focus on this aspect. By applying these conditions, it is expected that the analysis of DWPT operation near intersections will be more accurate compared to previous study. In addition, it is set to 33.3 m in consideration of the road width in Japan.

## 4. ANALYSIS FOR THE FREQUENCY OF DWPT CONDUCTED

In this chapter, we analyze the ratio of DWPT operation per drive cycle. The analysis method is almost identical for both cases, with the difference being the flag  $F_{dwpt\ i,j}(t)$  for each case. The flag  $F_{dwpt\ i,j}(t)$  is assigned a value of 1 when the conditions for DWPT operation are met, and a value of 0 when the conditions are not met. The subscript  $i$  indicates that the value belongs to the  $i$ -th vehicle in the database, while the subscript  $j$  means that the data point is the  $j$ -th sampling point for that vehicle. For instance,  $F_{dwpt\ [3,106]}$  indicates that the data belongs to the 3rd vehicle in the database and the 106th sampling point for that vehicle.

The number of DWPT operation  $V_{flag}$ , which represents the sum of the data points that satisfy the conditions for DWPT operation among all the data points stored for the vehicle, with a total number of  $x_j$  data points stored for the vehicle, can be expressed as follows:

$$V_{flag} = \sum_{j=1}^{x_j} F_{dwpt\ i,j} \quad (1)$$

$F_{dwpt\ i,j}(t)$  is the flag that takes a value of 1 when the conditions for DWPT are satisfied at time. Furthermore, the total sum of the time series data is  $V_{total}$ .

This represents the total number of data points  $x_j$  collected for the  $i$ -th vehicle over the time series. Therefore, the ratio of

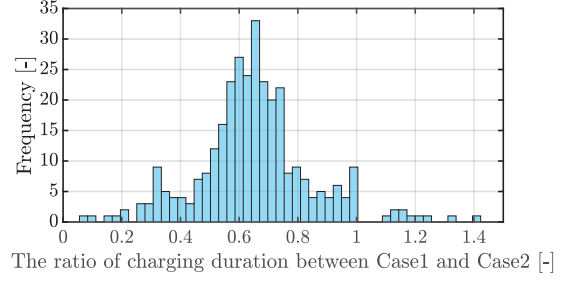


Fig.4. Ratio of DWPT conducted in the two cases  $R_{case}$ .

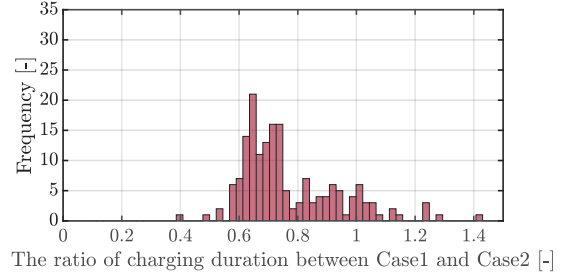


Fig.5. Ratio of DWPT conducted in the two cases  $R_{case}$  (Except for  $R_{dwpt1}$  and  $R_{dwpt2}$  exceeding 0.1 and 0.9).

DWPT conducted per drive cycle for the  $i$ -th vehicle, denoted as  $R_{dwpt}$ , can be expressed as follows:

$$R_{dwpt} = \frac{V_{flag}}{V_{total}} \quad (2)$$

By applying the above analysis to all vehicles, the frequency of DWPT operation can be calculated for each vehicle.

This paper verification analyzes the percentage of vehicle drive cycles in which DWPT was conducted in Case 1, the condition of the previous study, and in Case 2, the condition of this study.  $R_{dwpt1}$  be the fraction of DWPT conducted in one drive cycle for  $i$ -th vehicle under the conditions of Case 1 and  $R_{dwpt2}$  under the conditions of Case 2. This is obtained by Equation (2), respectively. Furthermore, to verify that the DWPT is consistent in Case1 and Case2, two ratios,  $R_{case}$  can be expressed as follows:

$$R_{case} = \frac{R_{dwpt2}}{R_{dwpt1}} \quad (3)$$

## 5. ANALYSIS RESULTS

In this chapter, we present the ratio of DWPT conducted per drive cycle for the same data in Cases 1 and 2. The ratios are calculated using Equation (3), and the results are analyzed to determine how Case 2 compares to Case 1 in terms of frequency.

From the results shown in Fig. 4, the data exhibits a normal distribution around 0.6, with a mean value of 0.66. Additionally, the variance is confirmed to be 0.051. Therefore, since the meaning is not close to 1, it is evident that the analysis results of this study differ from those of previous study. Moreover, since the

mean value is below 1, it indicates that the conditions for DWPT in Case 1, as established in previous study, are more easily satisfied, being 1.51 times larger compared to Case 2.

These results suggest that there are relatively few vehicles stopped near intersections within the analyzed vehicle dataset. This is because vehicles that stop on the shoulders of general roads are also judged to be stopped at the intersections with the previous study. Consequently, this situation may impact analyses regarding the minimum battery capacity required for EVs conducted in previous study. Future works will aim to further analyze the vehicle data used and explore the reasons behind the significantly larger differences observed between Cases 1 and 2.

Fig. 5 shows the results of data elimination. The data were eliminated from the results of Case 1 and Case 2 when the ratio of DWPT conducted on the vehicle per drive cycle was less than 0.1 and greater than 0.9. Eliminating this data improves the meaning to 0.78. In the future, we will further investigate appropriate values for data exclusion for vehicles.

## 6. CONCLUSION

In this study, we established a new condition based on the distance between vehicles and traffic signals to analyze the frequency of DWPT per drive cycle. While previous studies evaluated DWPT including instances of vehicles stopped outside intersections, this study focused exclusively on situations where the distance to the traffic signal is less than 33.3 m. As a result, the frequency of DWPT operation was found to be approximately 1.5 times higher on average compared to this study and the previous study, indicating that the conditions set in this study make DWPT less likely to occur.

The findings suggest that many of the stopping positions in the previous study were outside the intersection. This result has significant implications for assessments related to battery capacity, which influences the driving range of EVs. Future work will aim to clarify the reasons for the discrepancies observed between this study and previous studies through further data analysis.

## ACKNOWLEDGMENT

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