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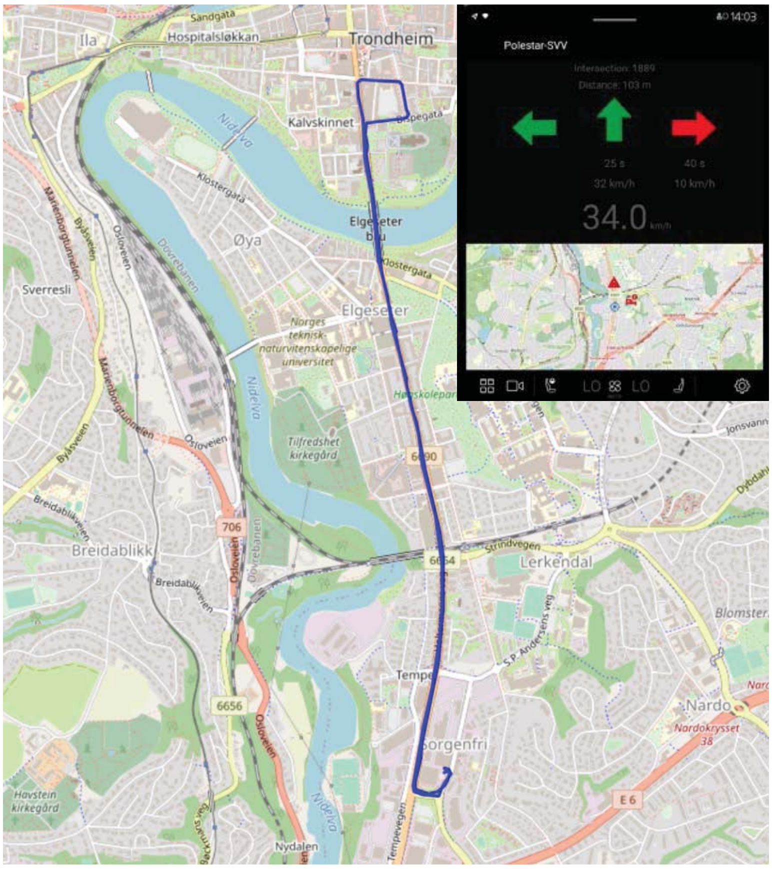

Report

Polestar 2 with Time-to-red/Green Light Optimal Speed Advisory (GLOSA) and Road Works Warning (RWW)

Evaluation of speed adaption with drivers in Polestar 2 vehicles

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SUMMARY
This report evaluates the efficacy of a Cooperative Intelligent Transport Systems (C-ITS) technology designed to communicate traffic light information to connected vehicles. As a part of the NordicWay 3 project, a sample of 15 drivers participated in a controlled study using an application displayed in the car's infotainment display. The app was developed to display traffic light status, road work warnings and recommended speed to optimize intersection crossing times. Participants completed two trips along a designated route, one without the app functionalities and one with the functionalities being active. During trips, vehicle data such as speed, energy influx and efflux within the battery system was collected. In addition, traffic light data was relayed as the car approached each intersection. After each pair of trips, the participant answered a survey about how they experienced the app's influence on their driving behaviour and how they evaluated interface quality. Survey responses towards the utility and functionality of the app were generally positive, with participants also stating that the app was helpful. Insights into vehicle data revealed a consistent behaviour in intersections whether the driver used the app or not. This indicates that the properties of the intersection itself could be the dominating factor influencing driver behaviour in this test. Despite some variance between drivers' perceived and actual measured benefits of the app, the participants underscore the potential of C-ITS technologies to contribute constructively to the driving experience.

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1 Introduction

This report presents work that has been conducted as part of the research project NordicWay 3, which is a collaboration project between the Nordic countries where the main objective is to test and pilot groundbreaking C-ITS technology in urban areas.

A specific such functionality is called Traffic Light Information – and allows intersections to relay information to connected vehicles. Such information includes the status of the traffic light, and information on the time when a status change is expected. Typically, TTG (time-to-green) is the implemented solution, however in this project time-to-red was chosen, on request from the client. Automotive apps can then use this information to recommend a speed for the driver closing in on the intersection, referred to as GLOSA (Green Light Optimal Speed Advisory) in the TTG case. For our time-to-red implementation, recommended speed was calculated. The vehicle's infotainment system can then display this information to the driver. Of interest to the NordicWay 3 project is whether such information can be of assistance to drivers. In this context, one way to evaluate the positive effects of such technology is to compare the driving patterns between drivers using the technology and drivers not using it. In addition, locations of road works warnings (RWW) were shown on a map in the infotainment system.

To facilitate such an investigation, the software company FourC designed an app that show various traffic light information in the vehicle's infotainment system. The app also collects time series data related to the driving of the vehicle. Using the app, several test drives were performed in a live traffic setting in the city of Trondheim, Norway over a period of two months from June to August 2023. In total, 15 individuals completed the test drive. First, to collect relevant baseline data, each participant drove the route without the information from the app being active. Then, the participants completed a second, separate trip along the same route in which the functionalities were active. In addition, the participants answered a survey immediately after they completed their test drive. The survey included questions on the participants assessment after they had experienced the test functionalities, e.g., if they adjusted their speed towards traffic lights based on the information they received.

First, in chapter 2, we describe the data collection process, including the collection of vehicle data and the survey data. Chapter 3 contains a presentation of the results. First, we present the vehicle data, focusing on the potential differences between the test drives using the functionalities and the ones completed without the information from the app being active. Subsequently, we present descriptive statistics from the survey results. Finally, in chapter 4, these results are discussed both separately and in relation to each other, to understand how the test functionalities were assessed by the test participants.

The scope and the number of participants in the practical test was somewhat reduced compared to the original plans. In this report we present the results as is, and recommend adding more dimensions, as time-to-green and more participants, in future tests to be able to conclude with confidence on the effect of such functionalities. However, the work does show some indications and trends that is worth commenting on, and the analysis also serve as a useful approach to continue and adapt in future tests as well. Furthermore, the test concerning RWW was held to a minimum, only appearing once and outside the driven route, and the participants reaction to this functionality should therefore be conceived more on a conceptual and expectational level, more than experience from an actual test. The NPRA did however an extensive demonstration in Lisbon 2023 with participants on the ITS Europe conference on RWW, although not documented in this report.

2 Data Collection

2.1 Vehicle Data

One of the main goals of this research involved investigating the behaviour of the drivers. This requires collecting data from the operation of the vehicle itself. In the following we will briefly present the developed application, the test set up and the data collected.

2.1.1 FourC Google Automotive App

In Figure 1 and Figure 2 pictures of the application are shown. The software displays three key pieces of information: the distance to the lights, the time remaining until the next red light for each direction, and the recommended speed to optimize traffic flow.

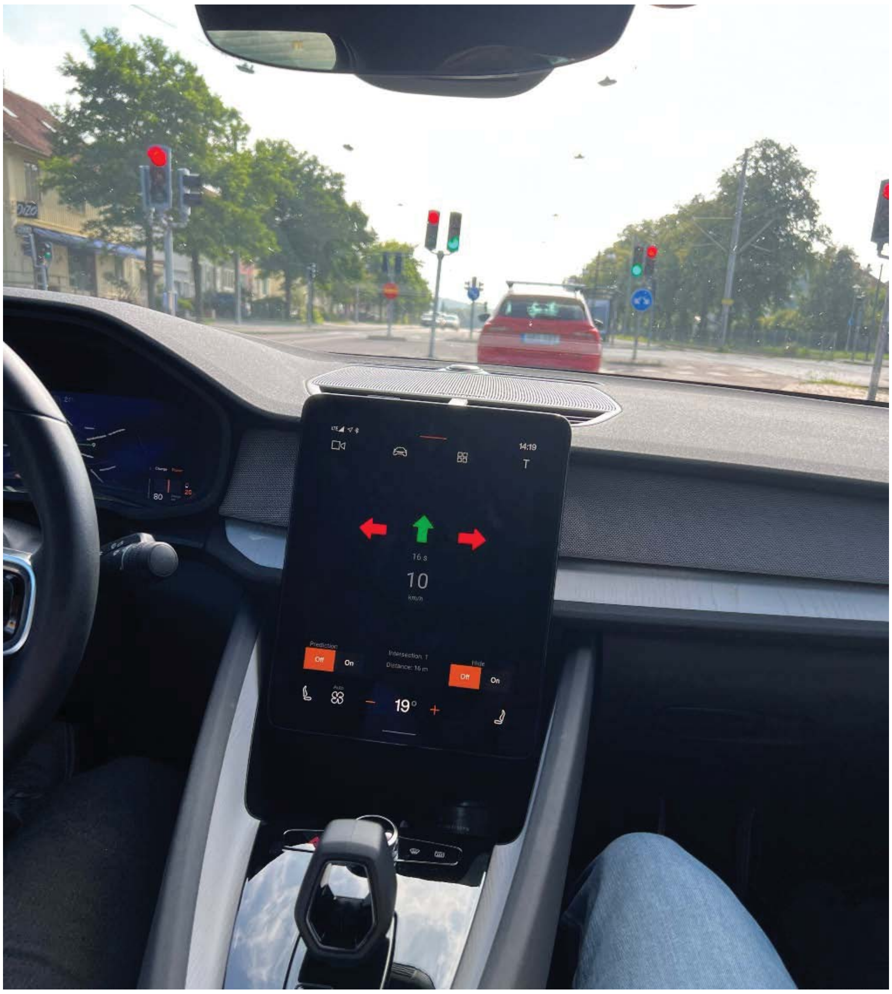


Figure 1: Interface

Figure 2: Interface close-up

2.1.2 Participant Setup

Each participant drove the test route two times. The participants were briefly informed on the experiment they were part in and its purpose. The first trip was driven without the app on the car's infotainment display. In contrast, the second trip was performed with the app showing various parameters about the intersection, such as time-to-red and recommended speed. Specifically, the application was designed to clearly convey: 1) the possible directions in the upcoming intersection, 2) an indication of the status of each direction in the intersection, 3) a recommended speed to arrive at the intersection before a status change. As previously stated, comparing behaviour between the two categories was an important research goal in this work. Data was collected for fifteen participants.

2.1.3 Test Setup

The route started in the Sorgenfri area of Trondheim, as seen in Figure 3. The driver would start by going southwards on Sorgenfriveien, before going right after entering the first roundabout. Immediately after, the driver would go right again in the first intersection of the trip. After this, the driver would drive straight along Holtermanns Veg and Elgeseter Gate passing ten intersections. Following the last of those ten intersections, the driver would cross the Nidelven river along Elgeseter bridge. After crossing the bridge onto The Prince's Street in central Trondheim, the driver would go right onto Bispegata. Next, the driver would go left twice to get back on the Prinsens Gate and drive back to the origin. In total, each driver would pass 23 intersections along the route.

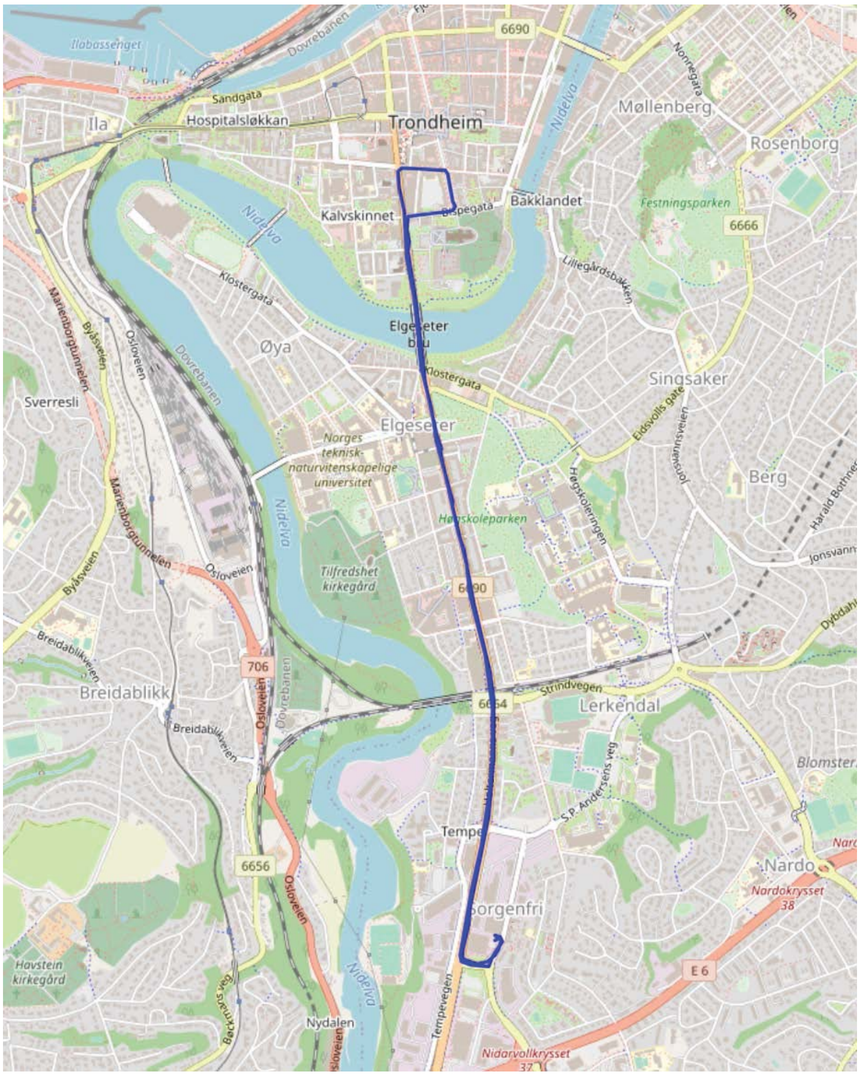


Figure 3: Test route

2.1.4 Car Data

For each trip various data about the car and the closest intersection was stored in time-series format. The various parameters can be grouped into three basic categories. Namely, these are location data, car information and intersection information.

1. **Car Information**
    a. *Latitude and Longitude*: These provide the geographic coordinates for the trip the car is travelling.
    b. *Timestamp*: This offers temporal information about when the specific data point was recorded.
    c. *Real Speed*: Indicates the actual speed of the car, from GNSS measurements.
    d. *Displayed Speed*: Shows the speed displayed on the car's dashboard.
    e. *Instant Charge*: Energy going in and out of the car’s battery. This means that when the car is braking, this would have a negative value, and a positive value when the car is accelerating.
2. **Intersection Information**
    a. *Intersection Timestamp*: When the data was relayed from the intersection.

b. *Directional Data*: Includes details such as the current phase for various directions at the intersection (e.g., left, right, straight).
c. *Latitude and Longitude*: The geographic placement of the intersection
d. *Time-to-red*: This is the time that it is estimated the intersection traffic light will stay green for.
e. *Recommended Speed*: This is the speed recommended by the app to be able to reach the intersection before it turns red.

2.2 Survey Data

To get insights into and understanding of the driver's assessment of the test functionalities described above, we developed a survey, which the test drivers answered after completing the test drive. All of the 15 test drivers conducted the survey via a smartphone. As all of the 15 test drivers conducted the survey, we have a 100 % response rate on all questions. The first respondent conducted the survey on the 27th of June 2023, and the last respondent conducted the survey after the final test drive on the 29th of August 2023, which means that the survey responses extend over a period of two months. The average response time was 3 minutes and 48 seconds.

We developed the survey by using the online survey provider Netigate. The survey covered four main topics and the following questions:

1. Background

- i. Gender
- ii. Age
- iii. Number of years with driving licence
- iv. Are you employed by the Norwegian Public Roads Administration

2. Assessment of functionalities

To what extent do you agree with the following statements:

- i. I am interested in new technology.
- ii. The presented interface was good.
- iii. The information that provides information at traffic lights worked well.
- iv. The information that provides information about road works worked well.
- v. The benefit of implementing the functionality that provides information at traffic lights in all vehicles will be great.
- vi. The benefit of implementing the functionality that provides information about road works in all vehicles will be great.

3. Location of information in the vehicle

Now we want you to consider which location would be most helpful.

- i. The information at traffic lights would be most helpful if it was located…
  - a. in the mid-console
  - b. in the dashboard (display behind the steering wheel)
  - c. in a head-up display (in the front window).
- ii. The information on road work warnings would be most helpful if it was located…
  - a. in the mid-console
  - b. in the dashboard (display behind the steering wheel)
  - c. in a head-up display (in the front window).

4. Driving behaviour

Now we want you to consider how the information from the app influenced your driving behaviour.

- i. To what extent did you adjust your speed towards traffic lights as a result of the information you received.
- ii. To what extent did you adjust your speed towards work warning areas as a result of the information you received.

On the first topic, background, two of the questions where open-ended where the respondents had to write their answer on age and number of years with driving licence. On the last two questions they had to select the response category which was right for them (on gender and if they are employed by the NPRA or not). These background questions were included to investigate possible differences across genders and the ones who are employed by the NPRA or not, and also if there were any differences between the respondents regarding their age and years with driving licence. However, as the number of respondents is relatively small (n = 15), it is challenging to perform such analysis.

For the three other topics in the survey, and their related questions, we used a 5-point Likert scale. For the second topic, and the six statements about their assessment of functionalities, the scale ranged from "Strongly disagree" to "Strongly agree" (1=Strongly disagree, 2=Disagree, 3=Neither nor, 4=Agree, 5=Strongly agree). Here the respondents had to consider to what extent they agree with the presented statements, e.g., on "The presented interface was good".

On the third topic, location of information in the vehicle, the respondents were asked to assess three possible locations for where the information about both traffic lights and road work warnings could be most useful. Here they had to assess the usefulness if the information was being located in the mid-console (as in the test), in the dashboard (display behind the steering wheel) and in a head-up display (in the front window). The scale ranged from "Strongly disagree" to "Strongly agree" on all six questions (1=Strongly disagree, 2=Disagree, 3=Neither nor, 4=Agree, 5=Strongly agree).

For the fourth and last topic, the respondents were asked two questions on how the test functionalities influenced their driving behaviour. First, they had to indicate to what extent they adjusted their speed towards traffic lights as a result of the information they received, and thus indicate to what extent they adjusted their speed towards road works as a result of the information they received. On both questions the scale ranged from "To no extent" to "To a very large extent" (1=To no extent, 2=To little extent, 3=Neither nor, 4=To a large extent, 5=To a very large extent). The final results from the survey are presented in chapter 3.2.

3 Results

3.1 Vehicle Data

The primary objective of analysing the vehicle data was to examine the potential variances in driving behaviour exhibited by the same drivers when operating with and without the use of the infotainment app. Hereafter, we will refer to this as the *driving settings*. Three parameters collected from the car reflecting on driving behaviour stand out from the dataset: real speed (**carInfo_realSpeed**), displayed speed (**carInfo_displayedSpeed**), and instant charge (**carInfo_instantCharge**).

In the following section we will statistically analyse the differences between the two full trips that each driver took. We will employ tools such as the paired t-test and effect size analysis. These are commonly used statistical methods to compare pairs of data.

3.1.1 Statistical testing on full trips

The data files were first categorized by the **carInfo_shownToUser** information, which signifies whether the driver see the information from the infotainment app. The paired t-test is then used to clarify if there were statistically significant differences between the speed variables **carInfo_realSpeed**, **carInfo_displayedSpeed**, and the instant charge variable **carInfo_instantCharge**.

To be precise, in these tests we compare the time series from whole trips with and without app to each other, i.e. one statistical test per driver. Any missing values were dropped form the corresponding variables. Outliers was assumed to not exist in the dataset. Normalization or standardization were deemed unnecessary for this test since this is a relative comparison. Also, keeping such data in the original scale can be better for interpretability.

For the 15 paired trips, (trip with and without app) it was found that both speed variables yielded statistically significant difference between the driver using the app or not. However, both positive and negative t-statistics were observed. This indicated that other factors probably influenced the speed of drivers more. However, for the instantCharge variable (throttle and braking), only half of the comparisons showed statistical significance. Once again, we see no conclusive trend, and both positive and negative t-statistics were represented among those.

In addition, an effect size test was conducted with the same pairs of data. A threshold (absolute value) was used to distinguish between small (0.2) and medium (0.5) effect sizes. For the speed variables, small or just below small effect sizes were found. This suggests that there are slight differences between the two conditions for the metrics we are comparing. However, the difference went in both negative and positive directions, indicating no clear pattern. For the instantCharge metric, the effect sizes are predominantly negligible, with values well below the threshold for small effect size. This implies that the differences between the two conditions are minimal for this metric.

To sum up, the statistical significance shows that there exist some differences between driving with and without app for some of the drivers, but not in any conclusive direction.

3.1.2 Comparing significant changes on full trips

With the knowledge we gained from the previous section, we can move on to more advanced methods to analyse the data. Since we already know the trips with and without the app turned on are quite similar in overall from the previous section, we will rather try to use an algorithm to "count" the number of *significant* changes in each trip. The algorithm counts a significant change depending on a threshold we set manually, i.e. were the rate of the change in driving speed somewhere on the trip is larger than some predefined values. We will use multiple methods: Dynamic threshold detection, rate-of-change analysis, and peak detection. To make the job easier for the algorithm, we also transform the data with smoothing techniques.

The instantCharge variable measured the electricity going in and out of the car's battery. Since this was an electric car, this effectively showed how the driver interacted with the throttle and brakes. Again, we chose to compare this variable between the two settings, with infotainment app or without.

First, an algorithm to detect changes based on a dynamic threshold was used. The difference between consecutive points was calculated for all trips. The threshold used varied between 2 ,3, 4, and 5 times the standard deviation of the differences. As such, the sensitivity of changes in the data could be adjusted. This was applied to all trips for the described thresholds. The table below shows the mean number of changes for the given dynamic thresholds, with and without the infotainment app. As can be seen in Table 1, the number of significant changes between the two driving settings is very similar regardless of the threshold.

Threshold	1	2	3	4	5
With app	456	297	203	136	93
Without app	458	297	202	137	90

Table 1: Mean number of detected changes in driver behaviour at various dynamic thresholds with and without infotainment app usage. Shows no significant different in the number of significant changes w.r.t. instantCharge for all trips.

Next, a rate-of-change approach was applied. For each value, the difference between itself and the previous value was divided by the previous value. This normalizes the rate of change and can be useful when there is high magnitude of variance in a time series. Ideally, this should detect relative shifts in the data. This approach gives a different perspective compared to the absolute differences, as it's more sensitive to changes in segments with smaller magnitudes. The number of significant changes using the rate of change approach varied between 23 and 97 for the data where the drivers had used the app. For the opposite case, the lowest count was found to be 32, while the highest count was 92. As such, this approach found slightly more significant changes in the case with the app.

In addition, a smoothing factor was applied to the data. A common way to apply smoothing is called moving average. With this, we wanted to reduce counting of minor fluctuations and emphasise broader, more significant changes. To apply moving average, each value is modified according to the values following it. The number of values used is called the window size. The sum of the values inside the window is then divided by the window size. We observe that depending on the threshold, there are slight variations as to whether more significant changes are found with or without the infotainment app.

Threshold (smoothed)	1	2	3	4	5
With app	1347	567	243	110	51
Without app	1350	557	232	111	61

Table 2: Comparison of significant rate-of-change and smoothed threshold variations in driver behaviour with and without infotainment app usage. Shows no significant different in the number of significant changes w.r.t. instantCharge for all trips.

Peak detection algorithms can be used to identify significant peaks and troughs in data. Usually, such algorithms should be useful to detect abrupt increases and decreases in a variable. We employ the find_peaks function from the scipy.stats Python package with default parameters. This is a relatively simple algorithm that searches for local maxima by comparing neighbouring values. The peak detection algorithm found *338 peaks and troughs* for the cases with the app, while *331* for cases without the app. Again, we see that there are very small differences, but a slight leaning towards more erratic behaviour while using the infotainment app.

Summing up this section, it seems that the data segments where the app was used tend to exhibit slightly more significant changes compared to the case without the app. This analysis reveals that while there are some slight differences between driving settings, the overall impact is relatively minor.

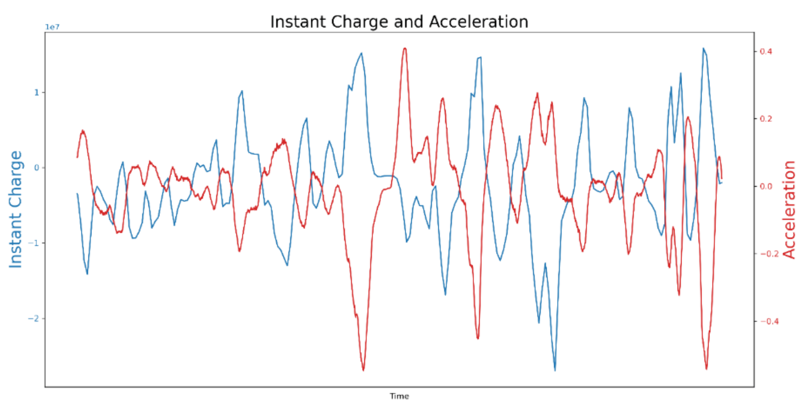
3.1.3 Establishing a relationship between battery charge and vehicle speed

So far, our analysis has been focused on two variables: The speed of the vehicle and the acceleration/braking of the driver taken from the car's battery (instantCharge). In the following section we show that when we differentiate the speed, we derive a signal describing the acceleration. When properly time-lagged, this derived time series strongly correlates with the instantCharge variable. It is intuitive to expect that the instantCharge and speed variables are correlated with each other. Obviously, the driver controls the throttle and brakes to accelerate or decelerate the car. However, for further analysis we want to explore how closely these variables are connected and how much lag there is in the correlation, to internally validate the data on these parameters.

We start by examining the Pearson correlation between the variables for one of the trips, without doing any feature engineering on the variables. We get a correlation coefficient of -0.24, which indicates a weak inverse relationship between the two variables; as one increases, the other tends to decrease slightly. This is in line with the intuitive expectation. When the car brakes, and energy goes into the battery, the speed of the vehicle also decreases.

Since we suspect that the influence of the battery charge on the speed is not instantaneous, we calculate a derivative of the realSpeed variable. This is performed by calculating the discrete difference and smoothing using a rolling window. This derivative now is a measure of the vehicle's acceleration. By visualizing this after finding the proper time-lag using cross-correlation, we clearly see a strong relationship between them, with a Pearson correlation of -0.79 (see Figure 4).

These results underscore the validity of the data that has been collected.



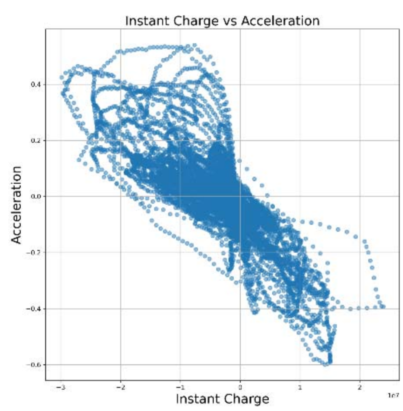


Figure 4: Line and scatter plot between acceleration (red) derived from the realSpeed variable and the instantCharge (blue) variable showing strong inverse correlation.

3.1.4 Comparison based on close-in to intersection

To get a better understanding of the driver behaviour when getting information from the infotainment system, an analysis of the driving behaviour closing in towards intersection was done. The route encompasses 23 intersections, which were each identified by its unique ID and accompanied by geographical coordinates. The dataset provided granular information about each intersection, such as the distance of the vehicle from the intersection, the current phase of the traffic light (Green, Red, or Unavailable), the recommended minimum speed to reach the intersection during the green phase, and the time remaining for the current phase.

The analysis revealed how vehicles interacted with intersections over time. Plots (see Figure 5) were generated to visually inspect the distance of the vehicle to the intersection, its real speed, and its instant charge, across the time dimension. These plots provided insights into how vehicles adjusted their speeds as they approached intersections, potentially in response to traffic light phases and recommendations.

In several instances, it was observed that vehicles adjusted their speeds as they approached intersections, potentially aiming to match the recommended speed and maximize the likelihood of passing through during the green phase. The "Phase Remaining" plots provided an understanding of the duration vehicles might have had to wait if they encountered a red light or the time left to pass during a green phase.

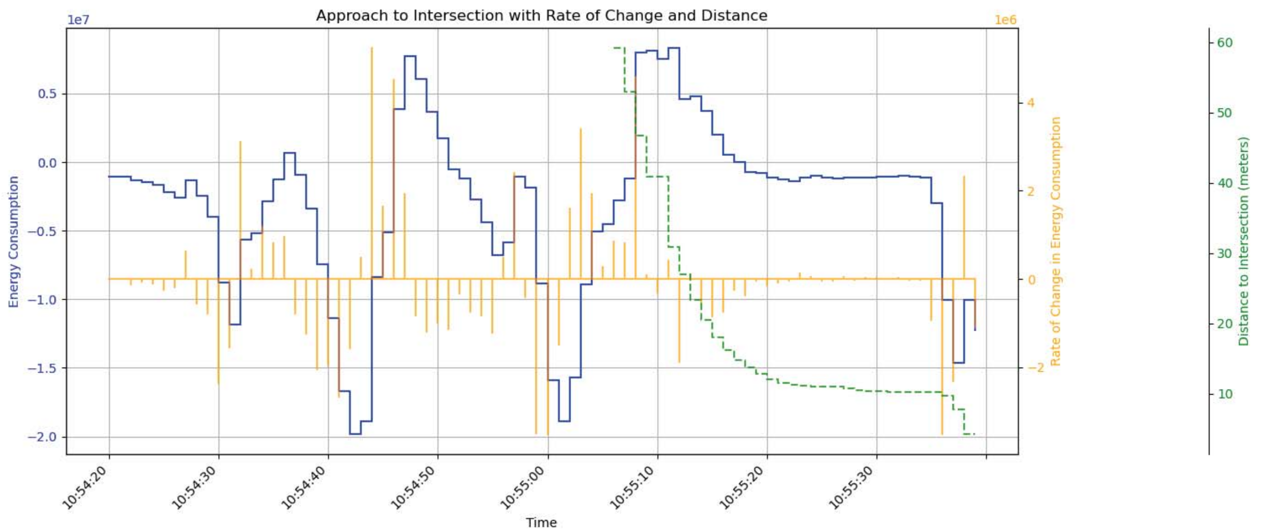


Figure 5: Example of car approaching intersection, showing the energy consumption (blue), rate of change in energy consumption (yellow) as well as the distance to the intersection (green).

Further, an analysis to better understand the broader patterns of how the drivers behaved at the different intersections was conducted. To achieve such a comparison, all trips were split into segments representing the approach to each intersection. Due to a multitude of factors both external and internal, each approach of an intersection happened at differing time spans, as well as speed and acceleration amounts. Since we wanted to compare speed and acceleration choices, it made sense to normalize all segments across the time dimension. This means that while in the real scenario, each segment took a different amount of time to complete the same distance, in the visualization we can inspect the behavior independent of the time it took. The segments were then grouped by intersection and color coded according to whether the trip had been performed with the infotainment app enabled (blue) or not (red).

After plotting the speed for each trip and comparing these with average speed choices, distinct patterns or groupings in the speed data began to emerge. We observe that most intersections belong to one of four categories, which we name after the pattern we find with visual inspection (see Table 3).

1: Speed Dip into Rapid Acceleration	2: Usually Green Light	3: Major Slowdown	4: No Clear Pattern

Table 3: Categories of driving patterns in intersections after visual inspection

We will now walk through each category and provide examples.

Category 1: Speed Dip into Rapid Acceleration

In the first category, we see the drivers going for a full stop or large speed reduction into rapid acceleration. This resulted in the driver being back to almost the same speed when it left the intersection (see Figure 6). We observe that most drivers greatly reduce their speed or come to a full stop, before accelerating back to full speed. We also show the location of Intersection 600102. Drivers would have to accelerate back to full speed quickly, and the data shows that they are usually back to full speed at the moment they pass it.

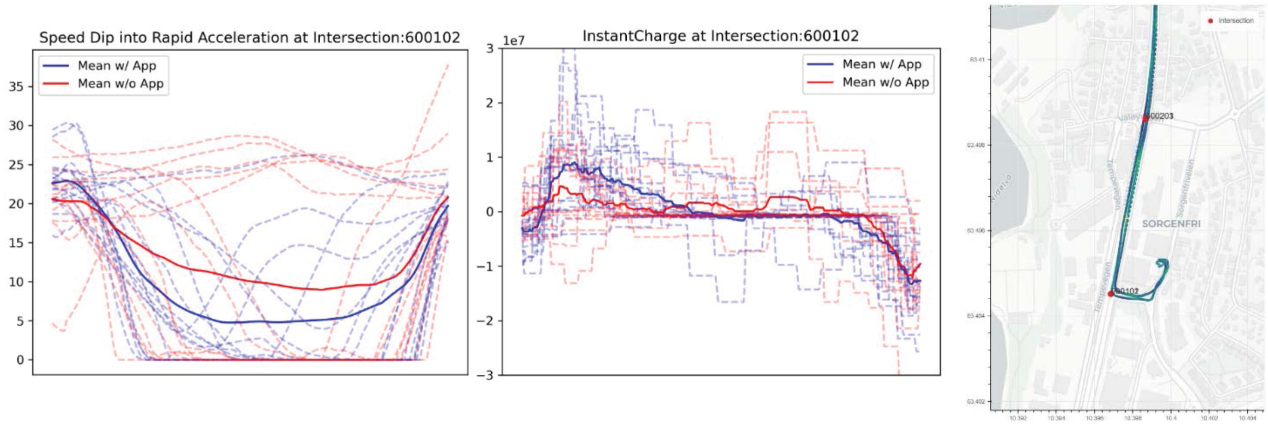


Figure 6: Typical example of the average speed and instantCharge, as well as geographical coordinates for the first “category”

Category 2: Usually Green Light

In the second category we observe a situation where most drivers encountered a green light and held a steady velocity (see Figure 7). We observe that most drivers maintain a steady speed, and mainly cruises or lightly brakes as they approach the intersection. We assume that this intersection (600303) is not often interrupted by pedestrians and the usually has a green light.

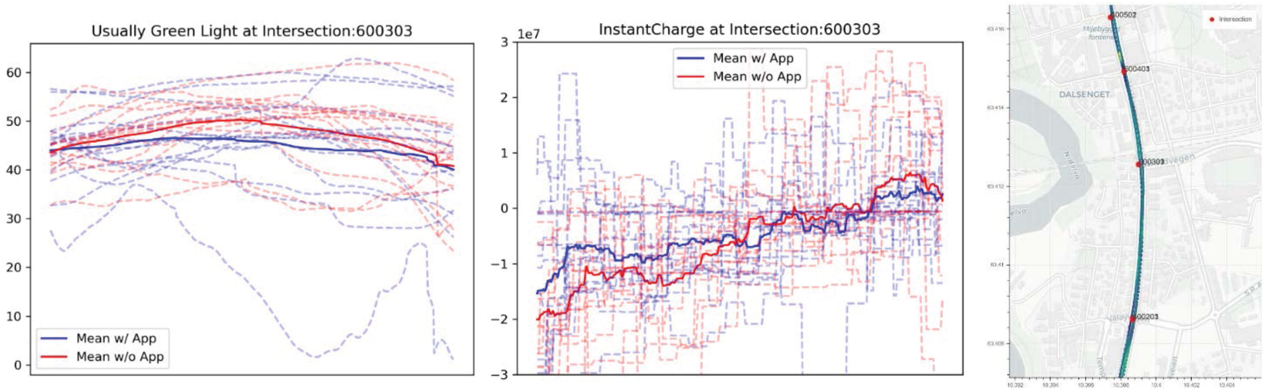


Figure 7: Typical example of the average speed and instantCharge, as well as geographical coordinates for the second "category"

Category 3: Major Slowdown

For the third case, it is observed that the driver appears to have a major slowdown and is leaving the intersection at a far lower speed than what they encountered it with (see Figure 8). This appears to be consistent whether the driver had fully stopped the vehicle or not. We see that the drivers are reducing their speed steadily, before entering the intersection with reduced speed compared to what they approached it with. We see that drivers must reduce their speed greatly, maybe because this is an area where many pedestrians are crossing.

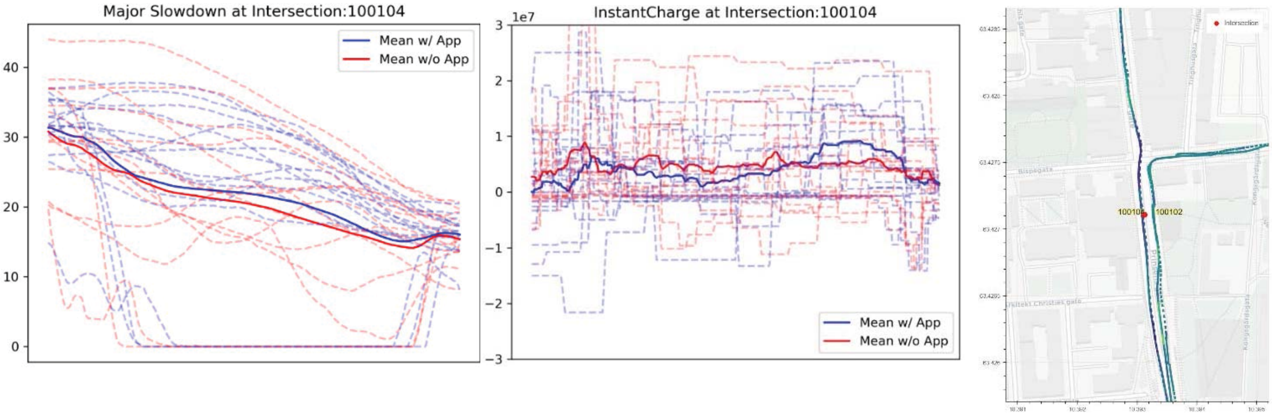


Figure 8: Typical example of the average speed and instantCharge, as well as geographical coordinates for the third "category"

Category 4: No Clear Pattern

Then, we designate a fourth category, where we cannot see a clear pattern, but there is some variability as to what the drivers encountered (see Figure 9). This intersection seems to have a lot of variability as to which traffic elements the drivers encountered. The various speed choices may be explained by crossing traffic or pedestrians, or a combination of both. Note however, that the mean of their behaviours is consistent across driving modes. we see a lot of variation in driving behaviour, even if the average is consistent. This can probably be explained by the fact that this intersection has many elements a driver needs to monitor.

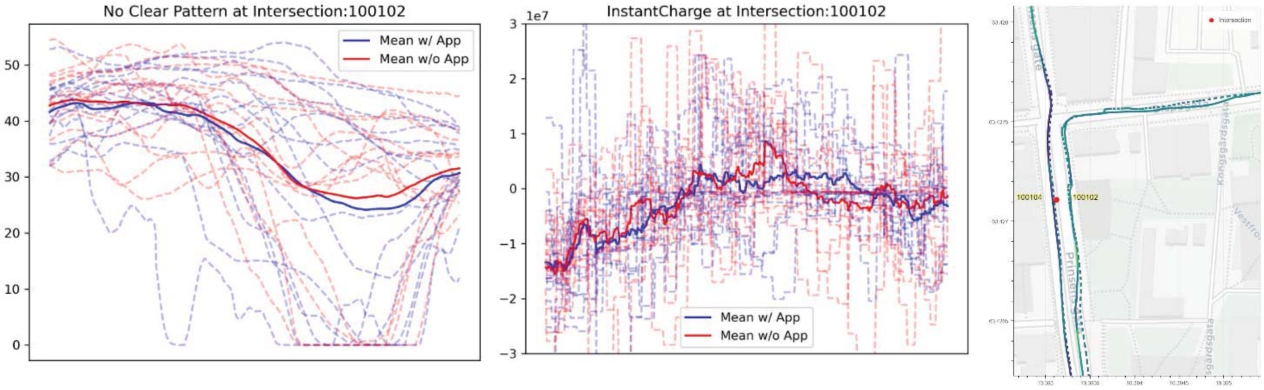


Figure 9: Typical example of the average speed and instantCharge, as well as geographical coordinates for the fourth "category"

Interestingly, across all four categories it is observed generally independent of whether the app was presented to the driver or not. We see that the average patterns are consistent across both modes. For consistency, we display the mean instantCharge for the same intersection. It is natural to assume that the speed of the vehicle is lag-correlated to the use of gas and braking. This manifests clearly in these comparisons, as we see slowdowns (braking) charging the battery, and acceleration discharging the battery. An overview of mean behavior for all intersections of the test trip can be found in the Appendix.

In closing, we notice that the behaviors of drivers are very dependent on the intersection itself. We observe that the inclusion of the infotainment app does little to influence the average driver across driving modes. Even if the amount of collected data samples is quite small (15 drivers for each driving mode), the pattern is quite clear, and more data would be likely to strengthen hypothesis.

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3.2 Survey Data

In this section we present results from the survey. As the total number of respondents is relatively small (n=15), we have not carried out statistical analysis based on this data. However, we will present descriptive statistics, looking for possible patterns in the data material. In chapter 4, parts of these survey results will be discussed in the context of the vehicle data presented in chapter 3.1. This will provide valuable insights into how the test functionalities, as was shown in the infotainment display in the vehicle, were assessed by the test drivers, it will gain insights into the usefulness of these functionalities and where such functionalities could be located in future vehicles.

As presented in chapter 2.2, the survey questions cover four main topics. These topics form the structure for the presentation of the survey results: 1. Background, 2. Assessment of functionalities, 3. Location of information in the vehicle and 4. Driving behaviour.

3.2.1 Background information

The section on background information included questions on gender, age, number of years with driving licence and whether the respondent is employed by the NPRA or not. These main characteristics shows that the sample is quite evenly distributed regarding age, number of years with driving licence and employment.

However, this is not the case for gender. As seen in Table 4 below, 11 out of 15 in the sample were male, while only 4 were female. Thus, male comprise 73 % of the sample.

Table 4: Gender

Categories	Frequency	%
Male	11	73
Female	4	27
Prefer not to answer	0	0
Total	15	100

The average age of the respondents is 44 years, where the youngest respondent is 23 years old and the oldest is 64 years. Regarding number of years with driving licence, the sample have on average held a driving licence for 24 years, where 5 years being the lowest and 46 years being the highest number of years with a driving licence.

The last question included in the background information was a question of whether they are employed by the Norwegian Public Roads Administration. As seen in Table 5, 8 out of 15 respondents work in the NPRA, thus comprising 53 % of the sample. Out of these eight NPRA employees, five of them are male, while three are female. For the remaining seven respondents, who do not work in the NPRA, we have no information on where they are employed. However, six out of these seven are male, while the last respondent is female.

Table 5: Are you employed by the NPRA?

Categories	Frequency	%
Yes	8	53
No	7	47
Total	15	100

3.2.2 Assessment of functionalities

The second topic in the survey was related to the respondent's assessment of the test functionalities. This topic consists of six statements, as seen in Figure 10 below, where the respondents had to consider to what extent they agreed with these statements (ranging from strongly disagree to strongly agree). Everyone in the sample (n=15) have answered to all six statements. Figure 10 is a compilation of the six statements, and each statement is described separately below.

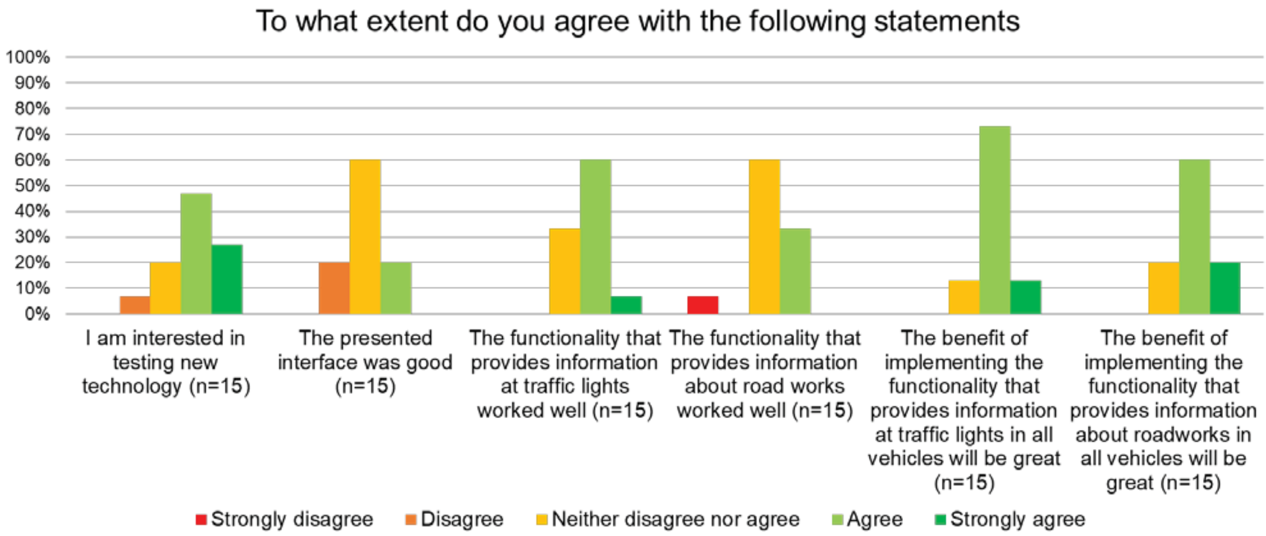


Figure 10: Assessment of functionalities.

By taking a closer look at each of the six statements, Figure 11 shows that on the first statement, "I am interested in testing new technology", 11 out of 15 (73 %) in the sample answered "Agree" or "Strongly agree". Three of the respondents (20 %) have answered "Neither nor", while the remaining respondent disagrees (n=1) with this statement. This result indicates that the respondents in this survey are on average quite interested in testing new technologies. This question was included in order to investigate if the respondents' interest in testing new technology have any significant importance for their assessment of the test functionalities. One possibility is that the respondents assess the technology in a more positive direction if they are interested in testing new technology and are positive towards new technology. It is also possible that the respondents' interest in testing new technology may have influenced their answer in a more negative direction, especially if their expectations to the technology wasn't met during their test drive. However, as the total number of respondents included in the survey sample is relatively small (n=15), it is challenging to run statistical analyses and present statistical relationships between the different variables.

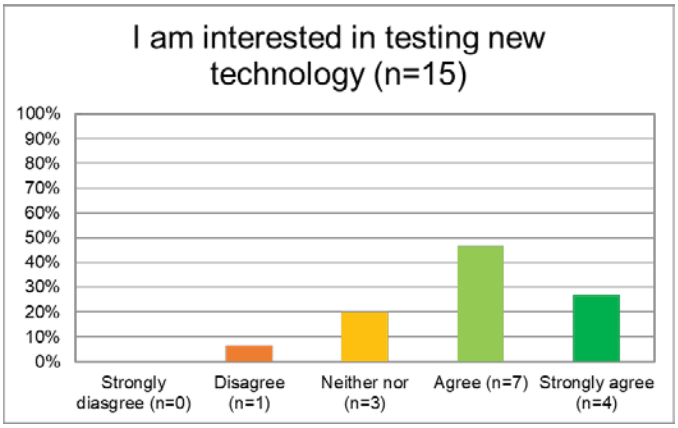


Figure 11: I am interested in testing new technology.

On the second statement that the respondents had to consider, “The presented interface was good”, 60 % (n=9) of the sample answered “Neither nor”. As seen in Figure 12, the remaining 40 % answered “Disagree” (n=3) and “Agree” (n=3). Based on this, it is quite clear that the presented interface was neither good nor bad according to the respondents.

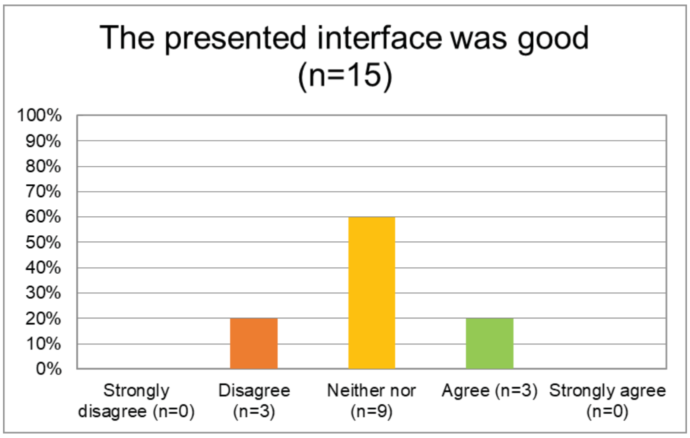


Figure 12: The presented interface was good.

Regarding the respondent’s assessment of the functionality that provides information at traffic lights, Figure 13 shows that nearly 67 % of the sample think that this functionality worked well during their test drive – 60 % (n=9) answered “Agree” and 6,67 % (n=1) answered "Strongly agree”. The remaining 33,33 % (n=5) answered "Neither nor”. In total, these results indicate that this functionality worked quite well according to the respondents.

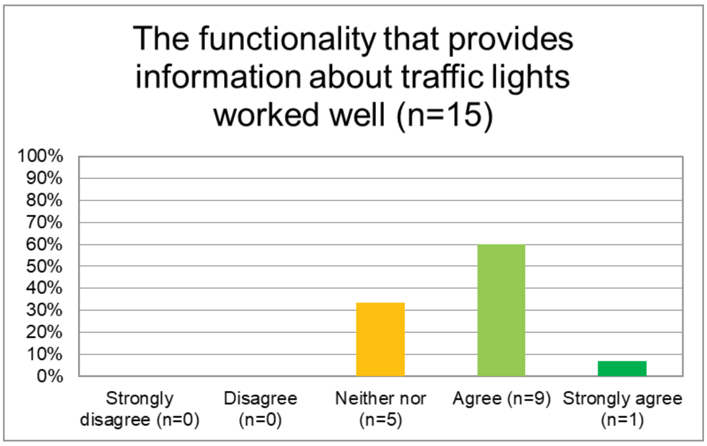


Figure 13: Information about traffic lights.

The respondent’s assessment of the functionality that provides information about road work is not as good as for the information at traffic lights. As seen in Figure 14, 9 out of 15 respondents (60 %) answered “Neither nor”. The remaining respondents answered "Agree” (n=5) and “Strongly disagree” (n=1). Although the respondent’s assessment of this functionality is slightly lower than for the functionality at traffic lights, their assessment is still more positive than negative.

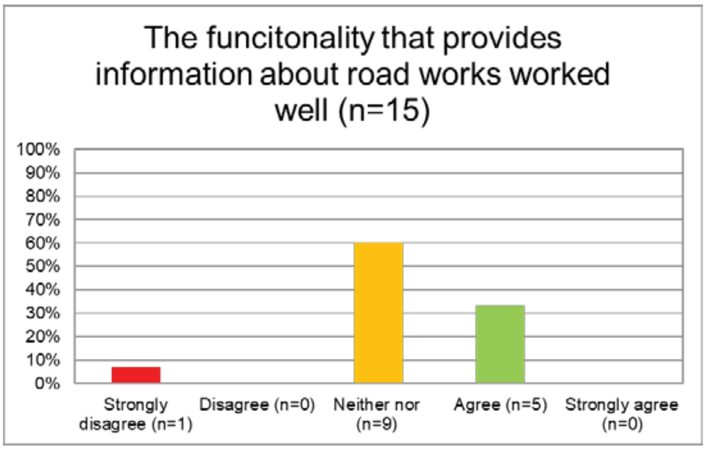


Figure 14: Information about road works.

The last two statements that the respondents had to consider under the second topic, assessment of functionalities, was related to the possible benefit of implementing both the functionality that provides information at traffic lights and the functionality that provides information about road work. By benefit we mean here the usefulness of these test functionalities. Overall, as seen in **Figure 15** and Figure 16 below, the respondents think that the benefit of implementing these functionalities will be quite good. For the functionality that provides information about traffic lights, as seen in Figure 15, 86,6 % of the sample have answered either "Agree" (n=11) or "Strongly agree" (n=2) regarding the benefit of implementing this functionality. The two remaining respondents (13,33 %) answered "Neither nor".

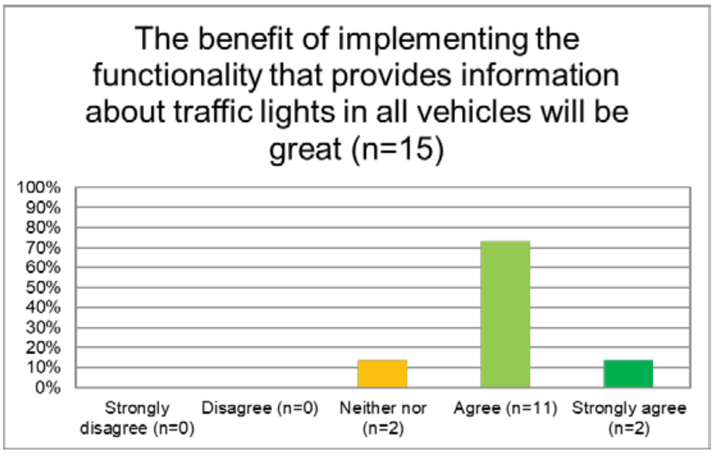


Figure 15: Functionality about traffic lights.

For the functionality that provides information about road works, as seen in Figure 16, 80 % of the respondents answered either "Agree" (n=9) or "Strongly agree" (n=3). The remaining 20 % of the sample (n=3) answered "Neither nor". These results indicate that the sample are positive towards, and see the possible benefits of, implementing these functionalities into future vehicles.

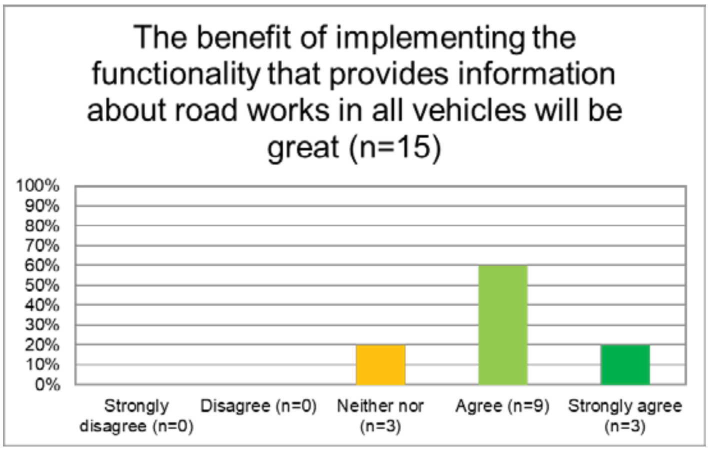


Figure 16: Functionality about road works.

3.2.3 Location of information in the vehicle

The third topic included in the survey consist of two questions regarding the location of information in the vehicle, regarding both the functionality that provides information about traffic lights and the one providing information about road work. On both questions the respondents had to consider three different locations and the helpfulness of each of them (ranging from strongly disagree to strongly agree). The suggested locations were; in the mid-console (as in the test), in the dashboard (display behind the steering wheel) and in a head-up display (in the front window).

Information on traffic lights

First, the respondents had to assess the three alternative locations for information about traffic lights, as seen in Figure 17. Overall, the respondents consider it as less helpful if the information was located in the mid-console (as in the test). Figure 17 is a compilation of the results for the possible locations for information on traffic lights. The result for each location is described separately below.

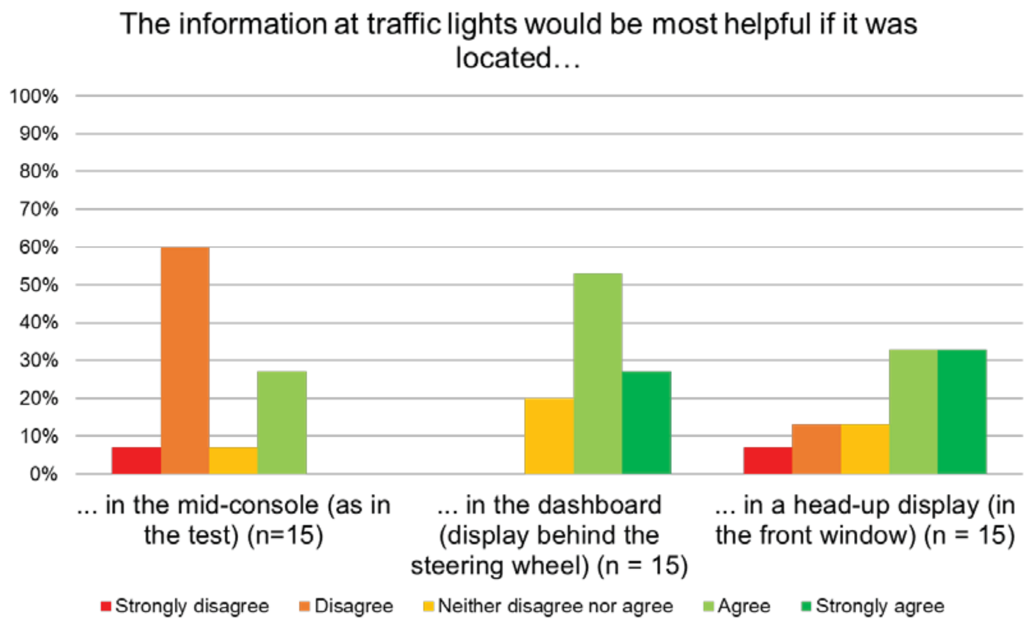


Figure 17: Location of information at traffic lights.

By taking a closer look at each of the three locations, Figure 18 shows that 60 % (n=9) of the sample “Disagree” on that the information at traffic lights would be most helpful if it was located in the mid-console. Only 4 out of 15 respondents (26,67 %) answered “Agree”, while the two remaining respondents have answered “Strongly disagree” (n=1) and “Neither nor” (n=1). None of the respondents have answered “Strongly agree”. This indicates, in a clear way, that the respondents do not see it as very helpful if the functionality is located in the mid-console, as in the test drive.

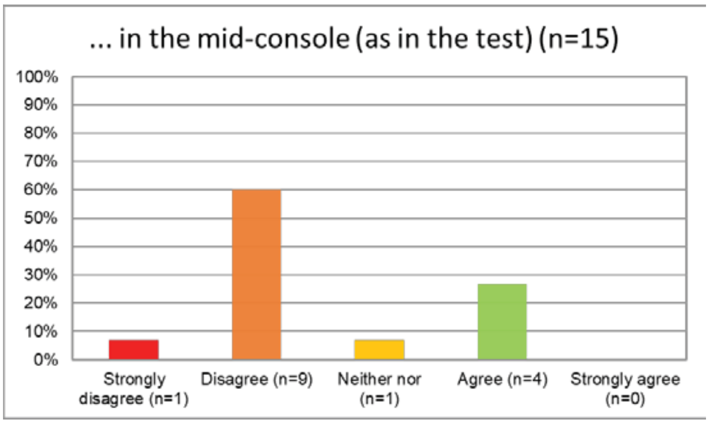


Figure 18: If located in the mid-console.

The respondents consider it as more helpful if the information was located in the dashboard (display behind the steering wheel). As seen in Figure 19 below, 80 % of the sample have answered “Agree” (n=8) or “Strongly agree” (n=4), while the remaining 20 % have answered “Neither nor” (n=3). Overall, this is the location that the respondents find most helpful, when considering where the information about traffic lights should be located.

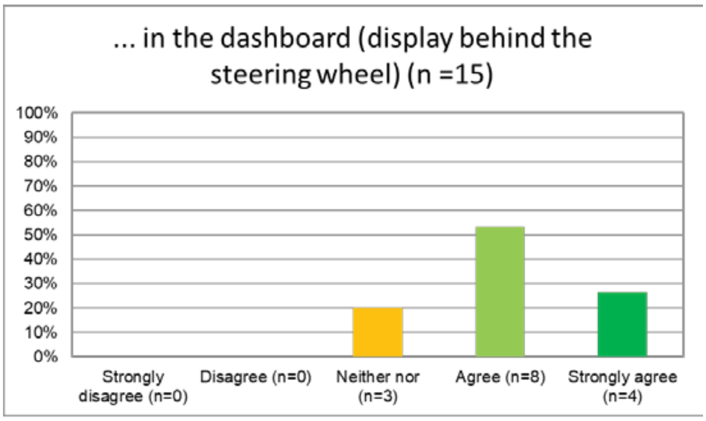


Figure 19: If located in the dashboard.

The third location that the respondents had to consider, was if the information was located in a head-up display (in the front window). The sample consider this location as more helpful than if the information was located in the mid-console, but slightly less helpful than if it was located in the dashboard. As seen in Figure 20, 10 out of 15 respondents have answered “Agree” (n=5) or “Strongly agree” (n=5), while two of the respondents have answered "Neither nor”. The remaining respondents have answered "Disagree” (n=2) and “Strongly disagree” (n=1).

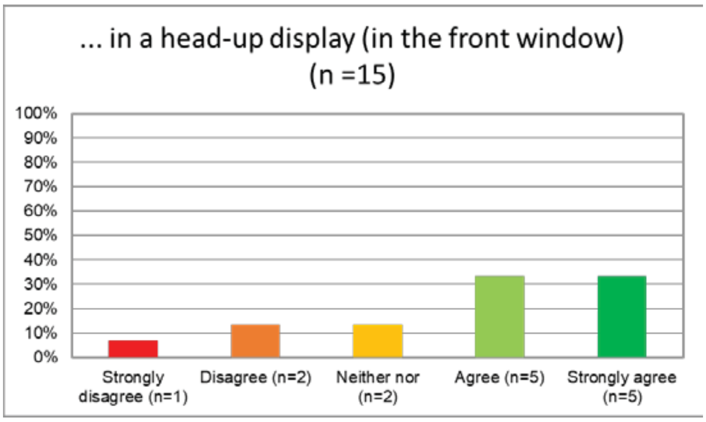


Figure 20: If located in a head-up display.

It is important to note that the respondents have tested one out of three locations for information on traffic lights. The fact that they only tested one possible location may have influenced their answers in a more negative direction. This is one possible explanation of why, as the survey results show, the respondents considered the mid-console (as in the test) as least helpful. It would clearly be beneficial to test all three possible locations, in order to get a more balanced assessment as to which of the three locations would be most helpful for the driver.

Information on road work warnings

After considering the location of information at traffic lights, the respondents had to assess the three alternative locations for information on road work, as seen in Figure 21. Overall, as for the respondents' assessment of location for information at traffic lights, they also consider it as less helpful if the information on road work was located in the mid-console (as in the test). Figure 21 is a compilation of the results for the possible locations for information on road work. The result for each location is described separately below.

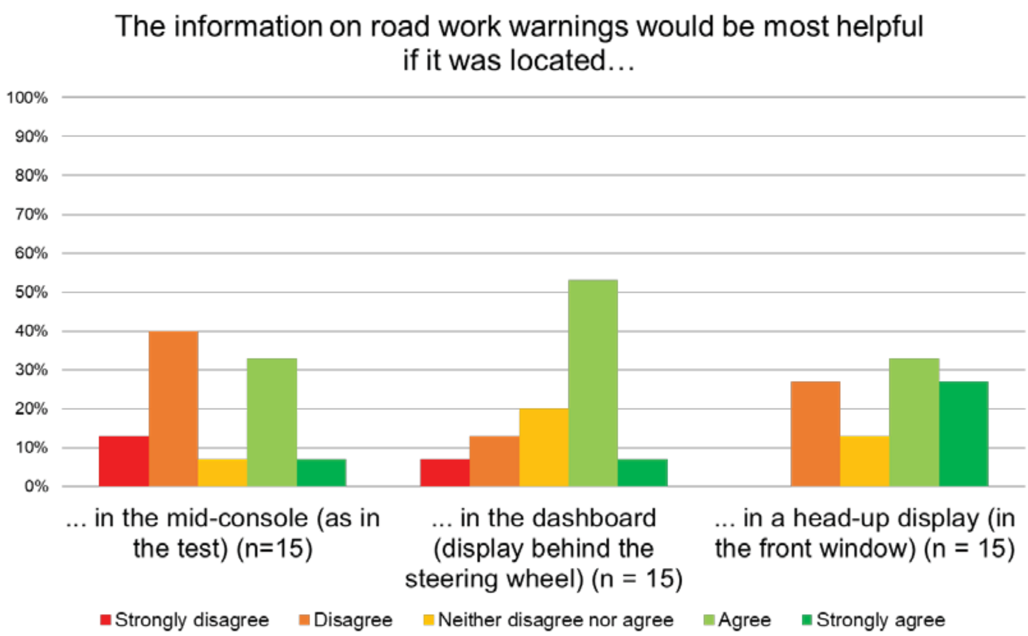


Figure 21: Location of information on road work.

Figure 22 shows that 53,3 % of the respondents have answered either “Disagree” (n=6) or “Strongly disagree” (n=2) on that the information about road works would be most helpful if it was located in the mid-console. 6 out of 15 respondents answered “Agree” (n=5) or “Strongly agree" (n=1), while the remaining respondent answered “Neither nor” (n=1). These results are slightly better than those regarding traffic lights and the location of information in the mid-console, as presented in Figure 18 above. However, of the three possible locations for information about road work, the respondents consider the mid-console as the least helpful.

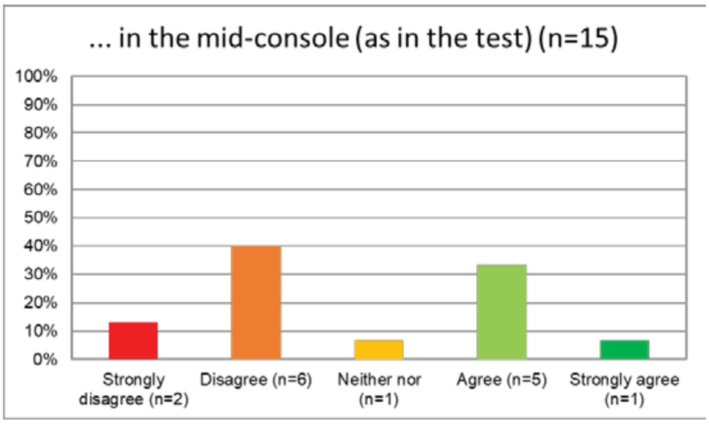


Figure 22: If located in the mid-console.

When considering if the information would be helpful if it was located in the dashboard, 60 % of the respondents have answered “Agree” (n=8) or “Strongly agree" (n=1), while 20 % (n=3) have answered “Neither nor”. The remaining respondents have answered "Agree” (n=2) and “Strongly disagree” (n=1), as presented in Figure 23. This is the location for information about road work, where the respondents have answered “Disagree” and “Strongly disagree” the least number of times, thus indicating that the dashboard could be the preferable location of information for road work.

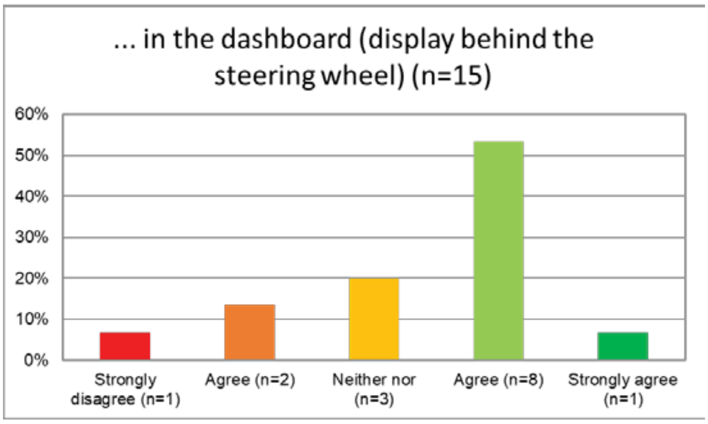


Figure 23: If located in the dashboard.

However, as seen in Figure 24, 60 % of the respondents have answered either “Agree” (n=5) or “Strongly agree” (n=4), when considering if the information would be most helpful if it was located in a head-up display. The sample consider this location as more helpful than if the information was located in the mid-console, but the results are quite similar to the previous one presented in Figure 23. The differences compared to Figure 23, is that even more respondents have answered “Strongly agree” (n=4), indicating that a head-up display could be most helpful location for information about road works. The six remaining respondents have answered “Disagree” (n=4) or “Neither nor” (n=2). None of the respondents have answered “Strongly disagree”.

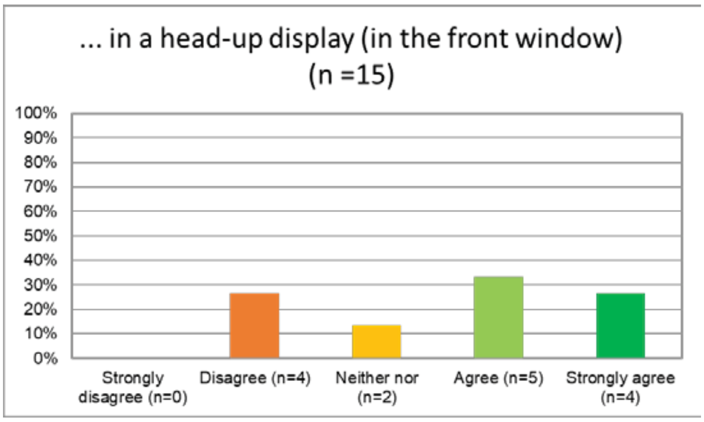


Figure 24: If located in a head-up display.

The respondents assessment of the three possible locations for information on road work show the same tendencies as the results for the information on traffic lights. Out of the three possible locations for information at road work warning, the respondents considered the mid-console (as in the test) as the least helpful. However, the respondents assessment of the test location (in the mid-console) was slightly more negative when considering the information on traffic lights than for the information on road work. One possible explanation for why the respondents consider the mid-console (as in the test) as the least helpful locations the fact that the respondents only tested one out of three possible locations, which may have influenced their answers towards a more negative direction. Therefore, to get a more balanced assessment of which location is the most helpful, it would be beneficial to test all three locations.

3.2.4 Driving behaviour

The fourth and final topic in the survey was related to driving behaviour. As presented in **Figure 25** and Figure 26, the respondents had to consider to what extent their driving behaviour was influenced by the information they received, specifically they had to consider to what extend they adjusted their speed related to the information they received both at traffic lights and about road work.

The results in Figure 25 show that 11 out of 15 respondents (73,3 %) answered "To a large extent", when considering if they adjusted their speed towards traffic lights as a result of the information they received. The four remaining respondents (26,7 %) answered "To little extent". This indicates that the information at traffic lights had an effect on the driving behaviour for the majority of the respondents.

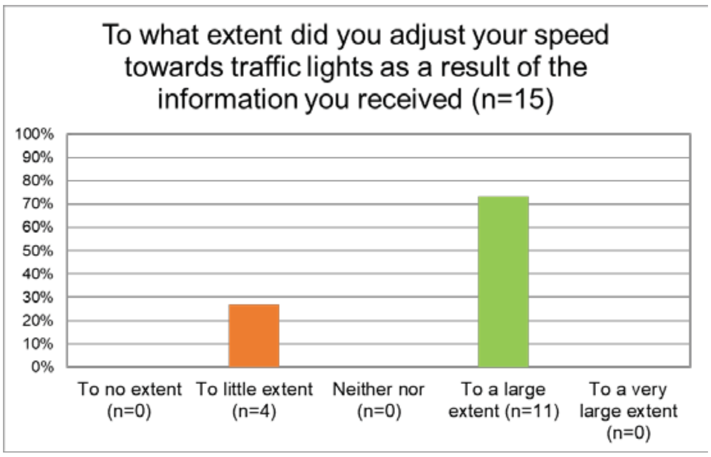


Figure 25: Adjusted speed towards traffic lights.

However, the results in Figure 26 does not show this same effect for the information about road works to any significant extent. Only two of the respondents have answered “To a large extent”, while eight of the respondents (53,3 %) have answered "Neither nor”. The five remaining respondents have answered “To little extent” (n=2) or “To no extent” (n=3). This indicates that the respondents did not adjust their speed towards road work to any particular extent as a result of the functionality that provides information about road work.

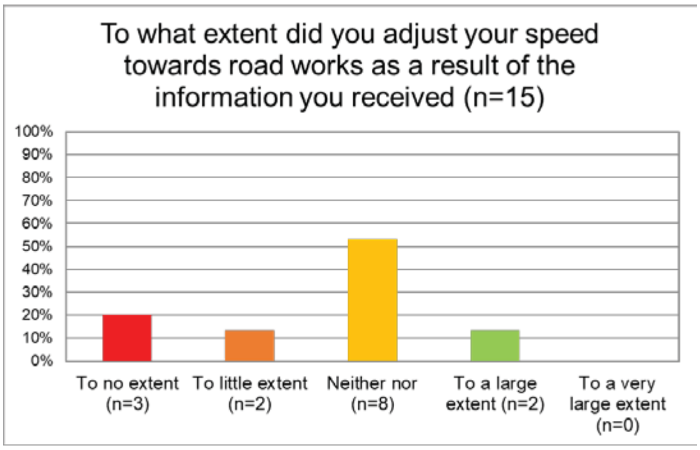


Figure 26: Adjusted speed towards road work

4 Discussion and Conclusion

In this study, we have used a multifaceted approach to investigate how the participants' driving behaviour was influenced by the information they received from the vehicle's infotainment system. We have used both vehicle data as well as survey data. First, the participants drove the test route without the information from the app being active, before completing a second trip along the same route in which the functionalities were active. In addition, the participants conducted an online survey immediately after they completed the test drive.

The result from the survey indicates that most of the drivers adapted their speed driving towards the intersection with the infotainment app being activeø These differences between the results from the vehicle data and the survey data is an interesting result, as it indicates that the participants think the infotainment app had greater influence on their driving behaviour than the vehicle data actually shows. It is, however, important to stress that the participants conducted the survey right after they completed the test. Unlike the vehicle data, which precisely shows how they drove during the test drive, the survey data consists of the participants subjective experience with the functionalities and how they drove during the trip. They are part of a research project and at this point in time the participants have just completed their test drive, which may have influenced their answers.

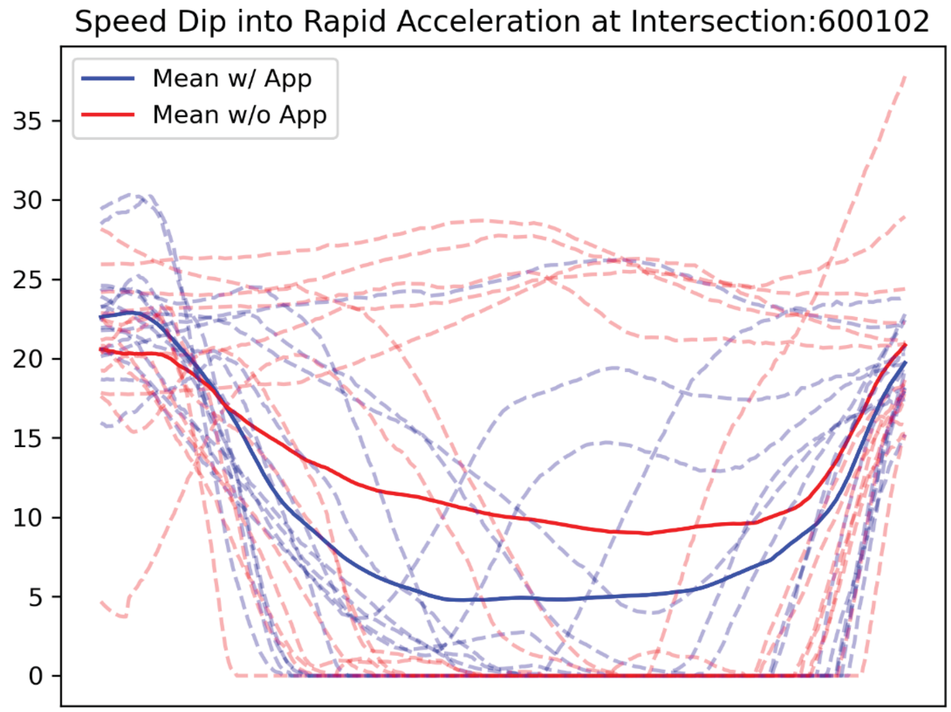
In this regard, it is interesting that the majority of the participants considered the mid-console (as the infotainment display in the test) as the least helpful location for information. Out of the three possible locations, the participants considered the dashboard (with an integrated front window display) as their preferred and most helpful location. It is, however, important to repeat that the participants tested only one location during their test drive, which may have influenced their answer. It would be beneficial to test several locations in order to get a more balanced assessment as to which location would be the most helpful for the driver when using such functionalities. However, the survey results show that the participants are clearly positive towards implementing such functionalities into future vehicles, thus indicating that the participants have positive experiences from the test drive and see the possible benefits of such functionalities, even if the infotainment display in the test was not their preferred location. This emphasises the importance of location for such functionalities, and the need to take the users assessment and experiences into consideration when deciding where to locate these functionalities into future vehicles. In this way, the functionalities and its interface will benefit the individual drivers and the society as a whole.

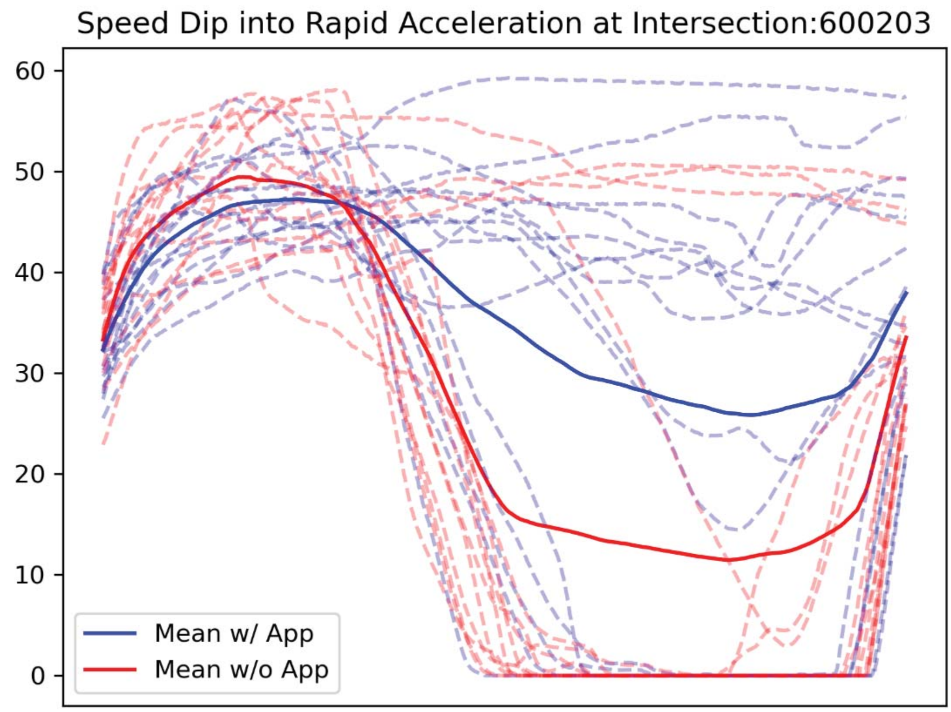
The fact that driver behaviour in intersections is consistent across both driving settings underscores how influential local road conditions are for motor vehicle operators. In addition, the apparent discrepancy between self-reported survey data and vehicle data highlights the difference between perceived and actual driving behaviors. It also suggests that the drivers' understanding of in-vehicle information is not necessarily consistent with reality. Finally, all these aspects point to the importance of system placement and design in influencing driver actions. This calls for further investigation into how drivers process information, which can inform the development of safer and more effective driver assistance systems.

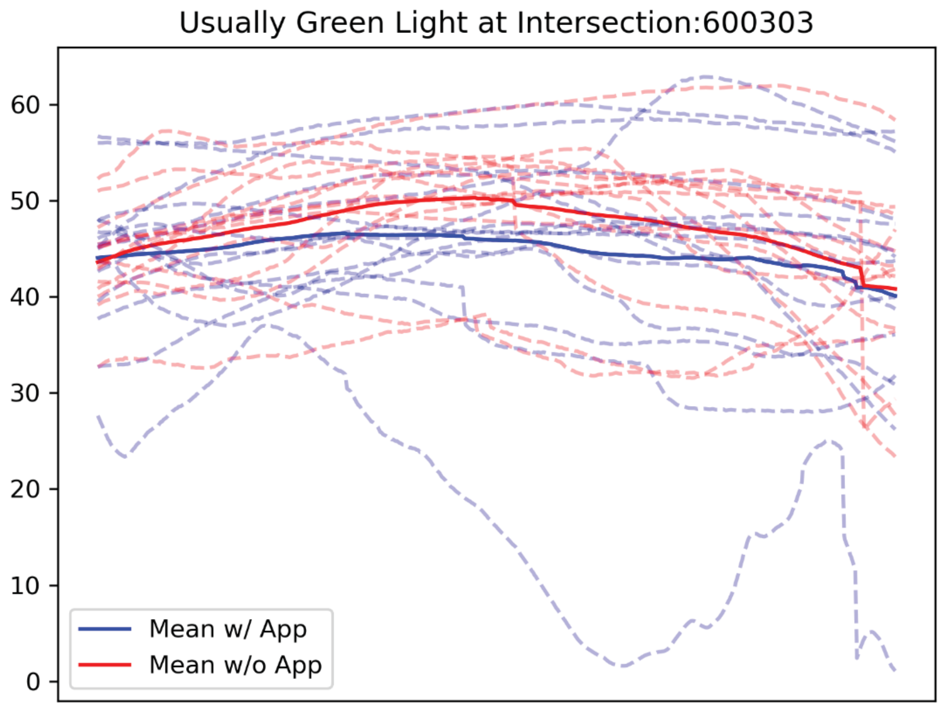
5 Appendix

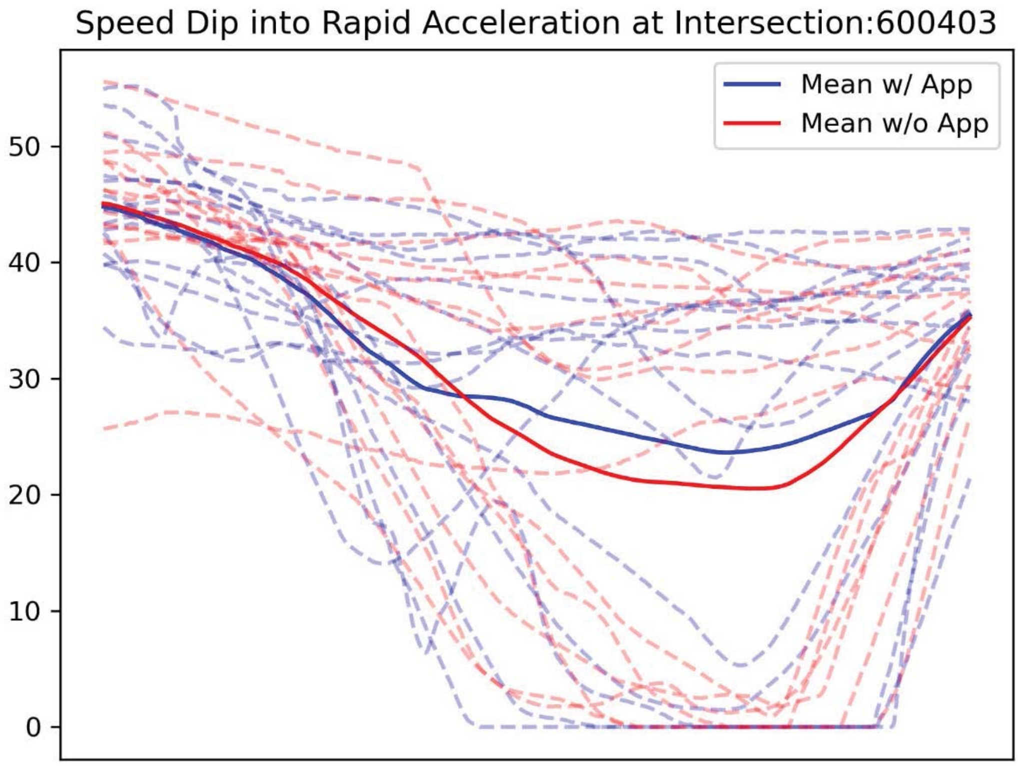
For clarification, we here provide the average driver speed and instantCharge patterns for all intersections that was part of the data collection.

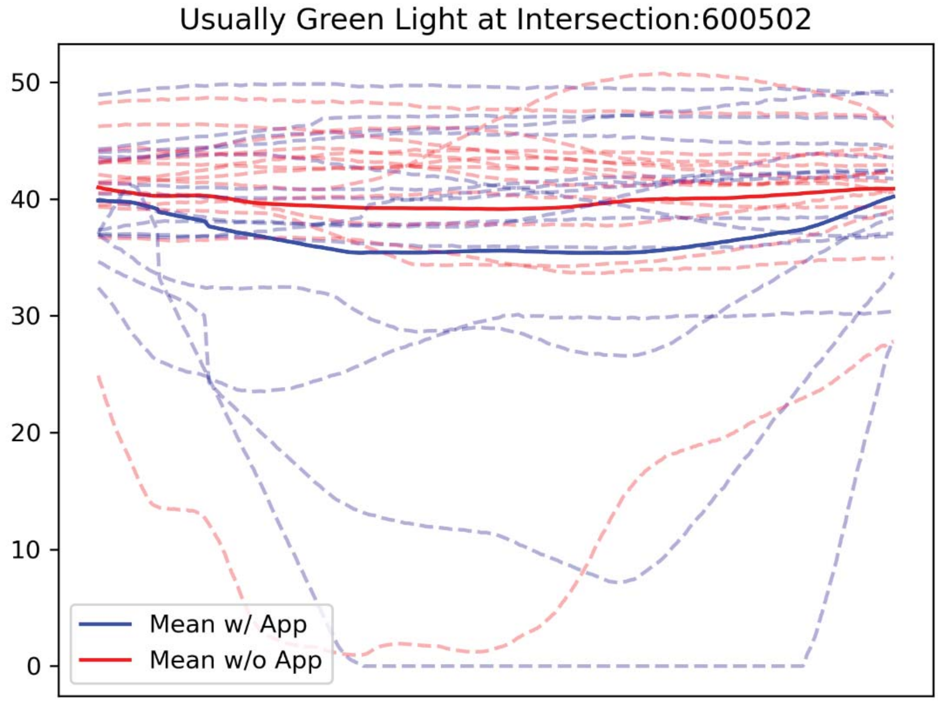
5.1 Average speed patterns for all intersections

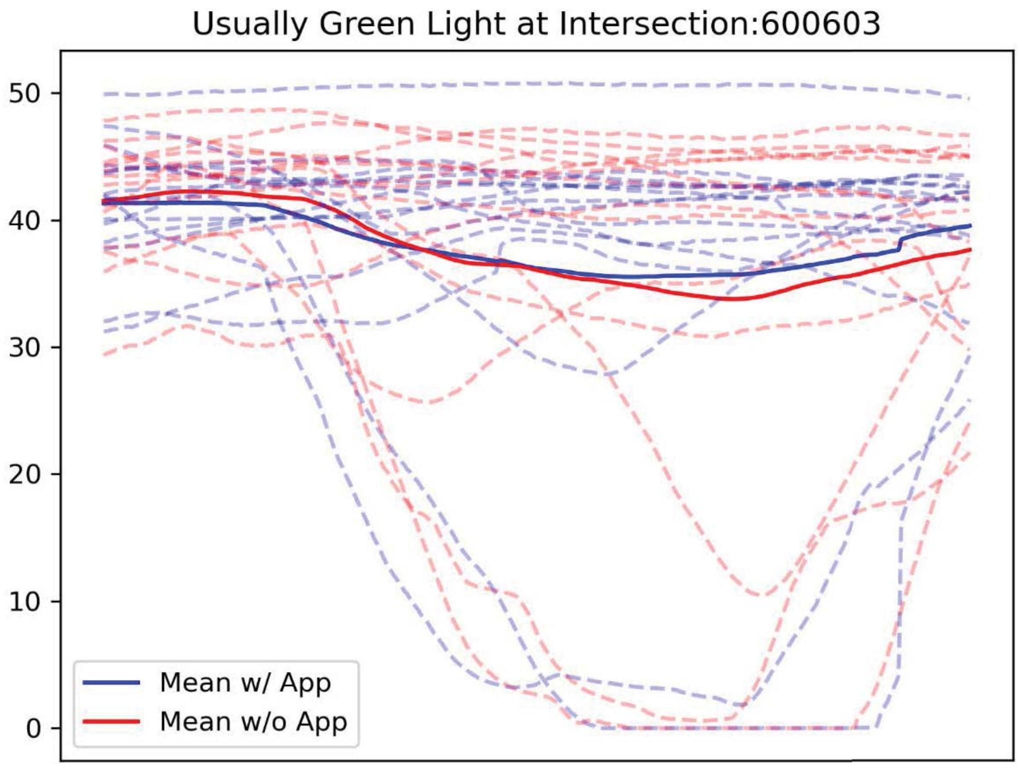


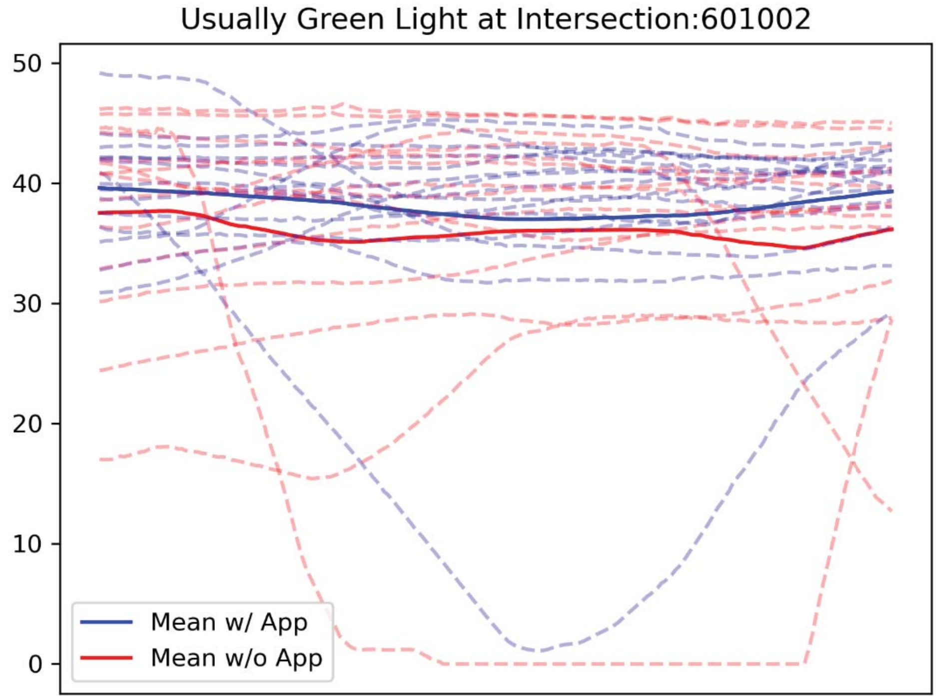


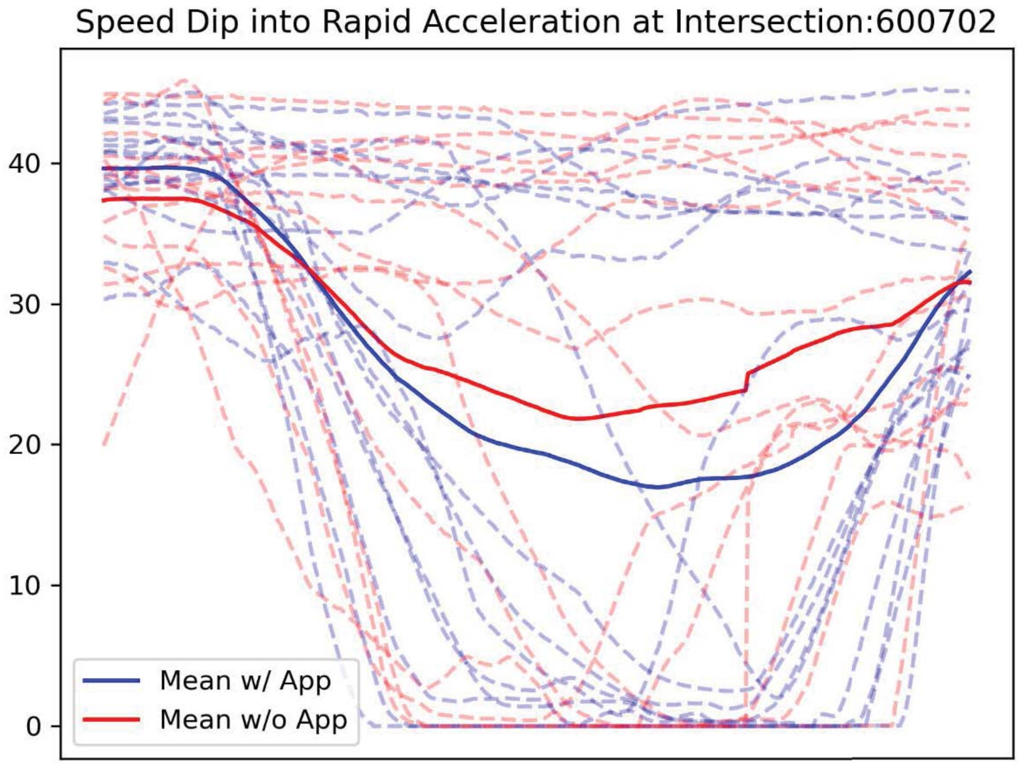

Usually Green Light at Intersection:600303
60
50
40
30
20
10
0
Mean w/ App
Mean w/o App

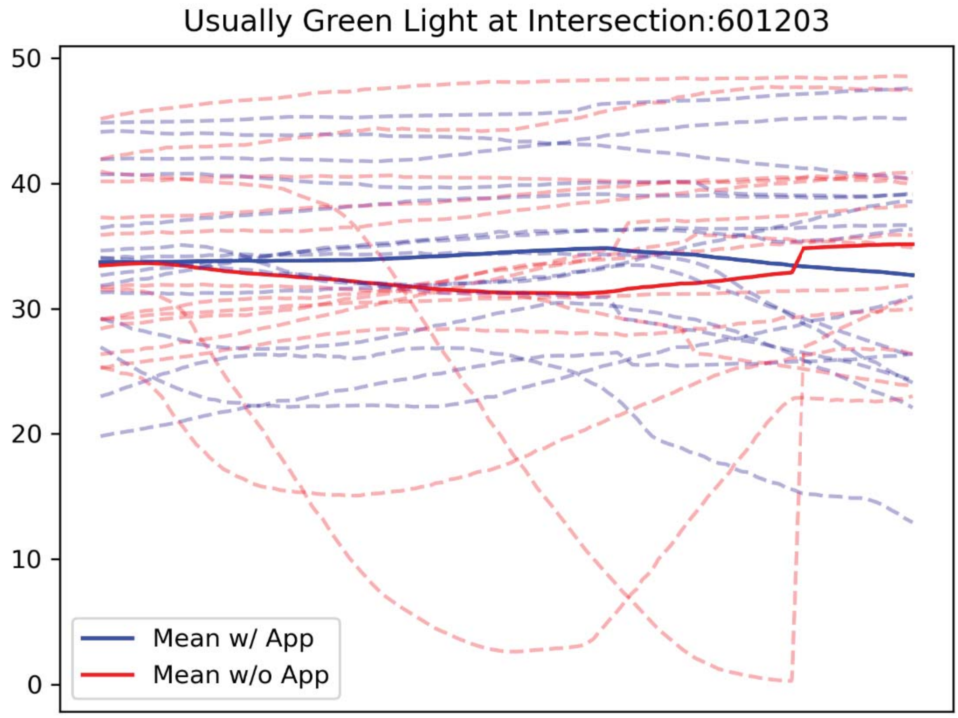

Speed Dip into Rapid Acceleration at Intersection:600403
50
40
30
20
10
0
Mean w/ App
Mean w/o App

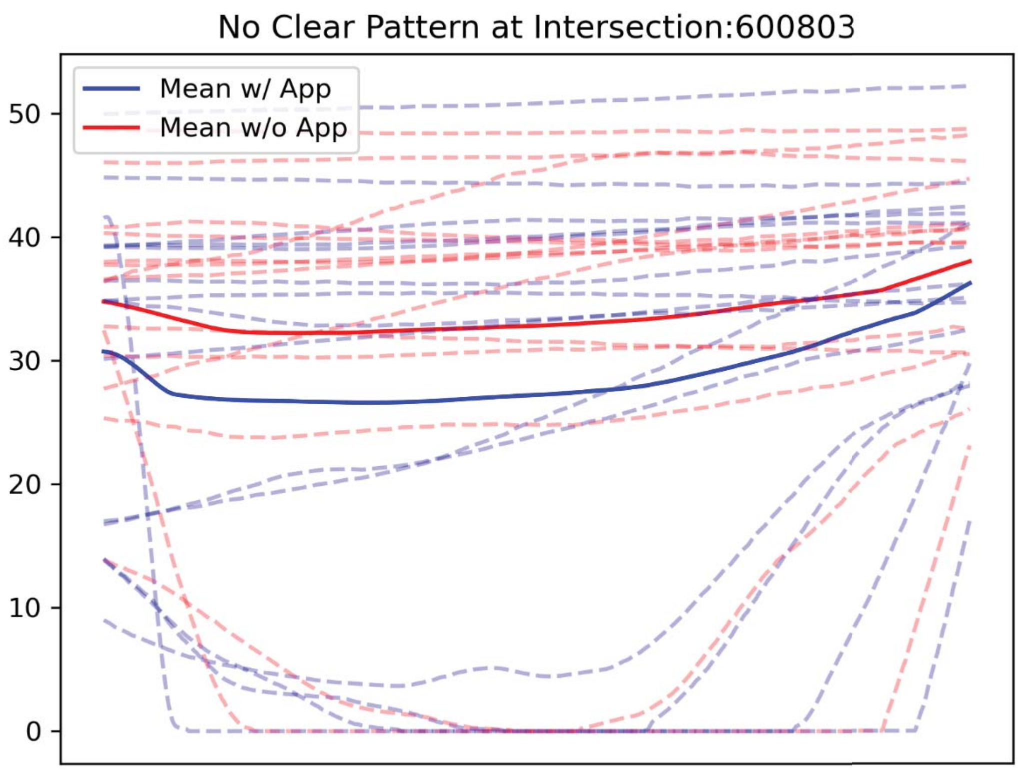

Usually Green Light at Intersection:600502
50
40
30
20
10
0
Mean w/ App
Mean w/o App

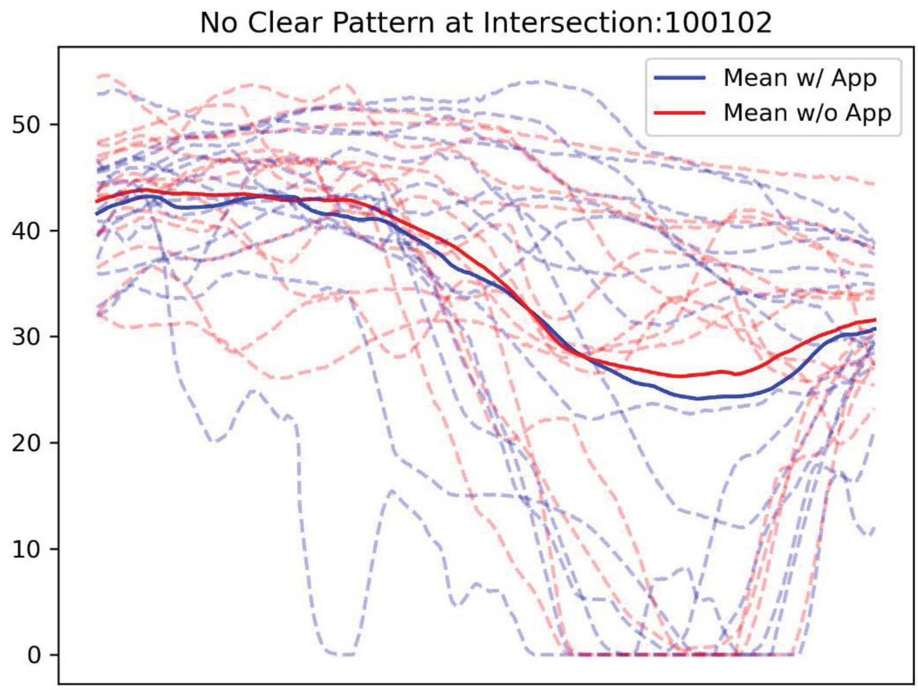

Usually Green Light at Intersection:600603
50
40
30
20
10
0
Mean w/ App
Mean w/o App

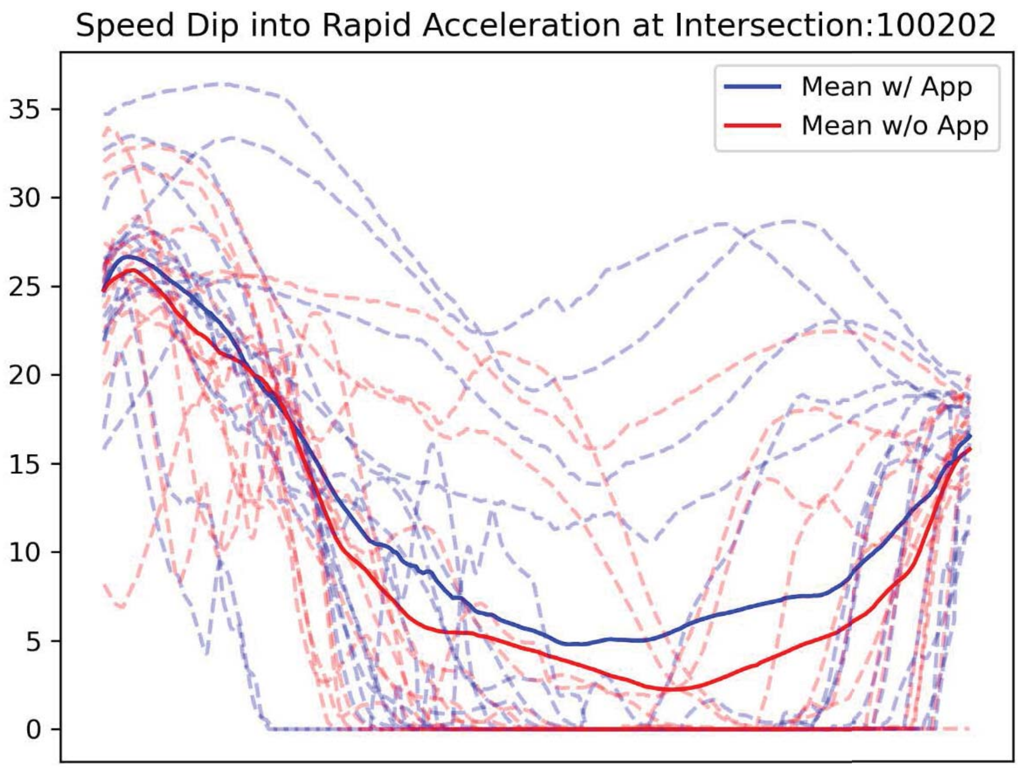

Usually Green Light at Intersection:601002
50
40
30
20
10
0
Mean w/ App
Mean w/o App

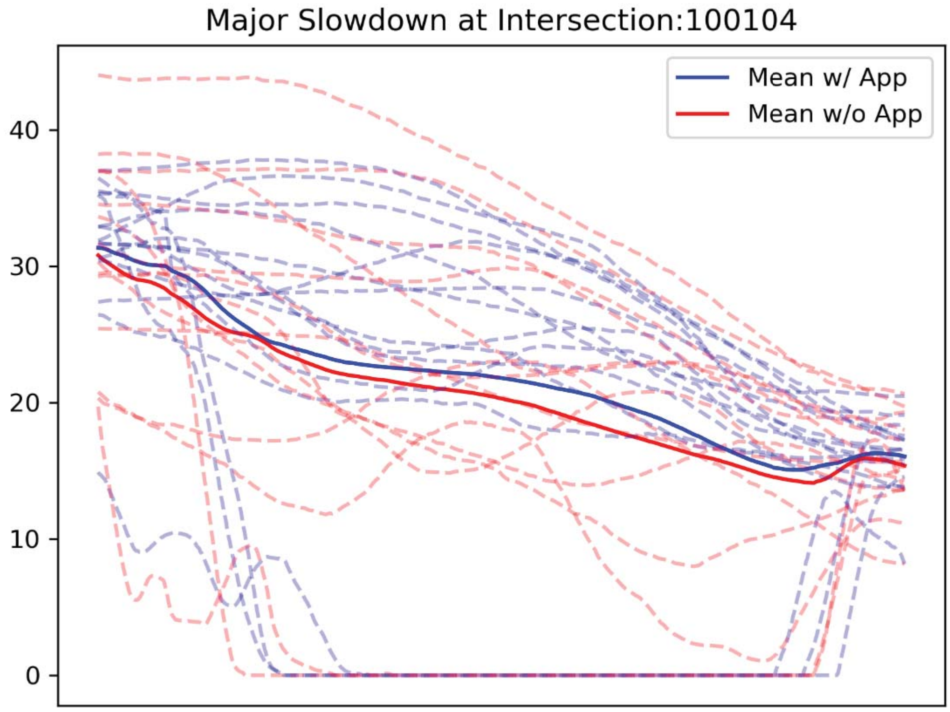

Speed Dip into Rapid Acceleration at Intersection:600702
40
30
20
10
0
Mean w/ App
Mean w/o App

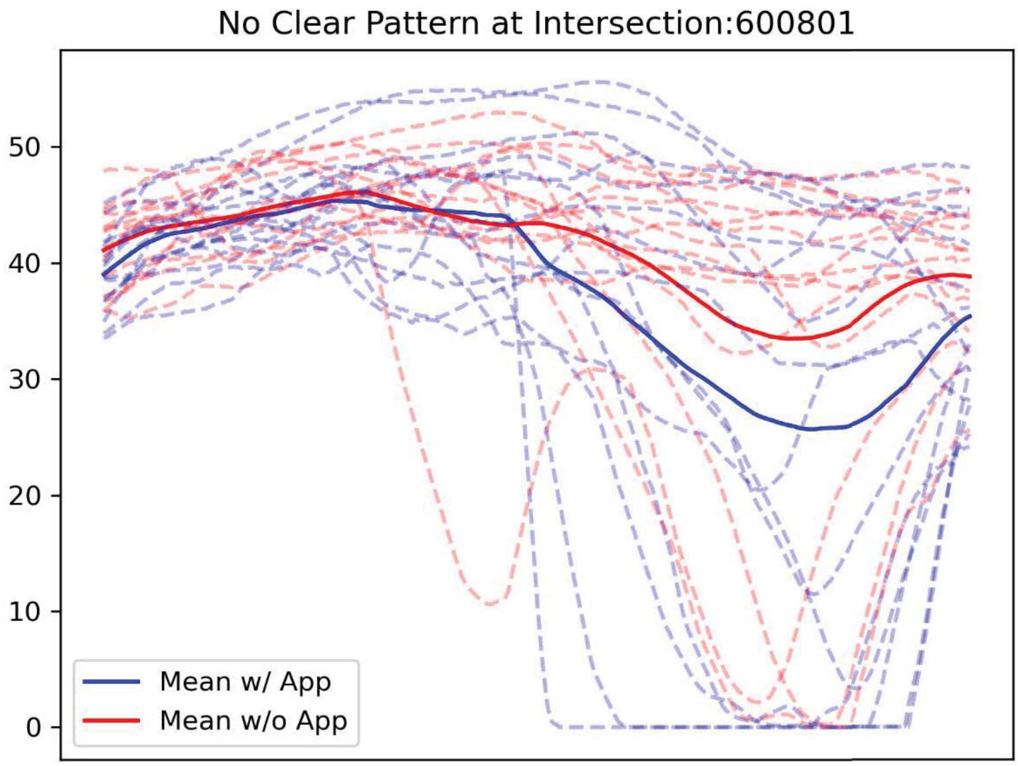

Usually Green Light at Intersection:601203
50
40
30
20
10
0
Mean w/ App
Mean w/o App

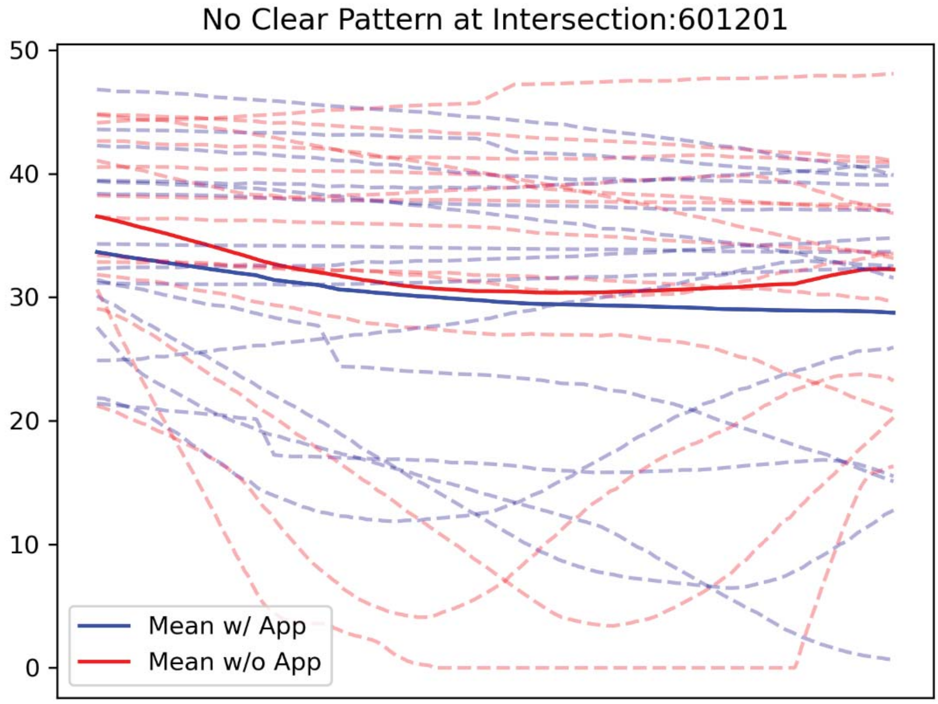

No Clear Pattern at Intersection:600803
50
40
30
20
10
0
Mean w/ App
Mean w/o App

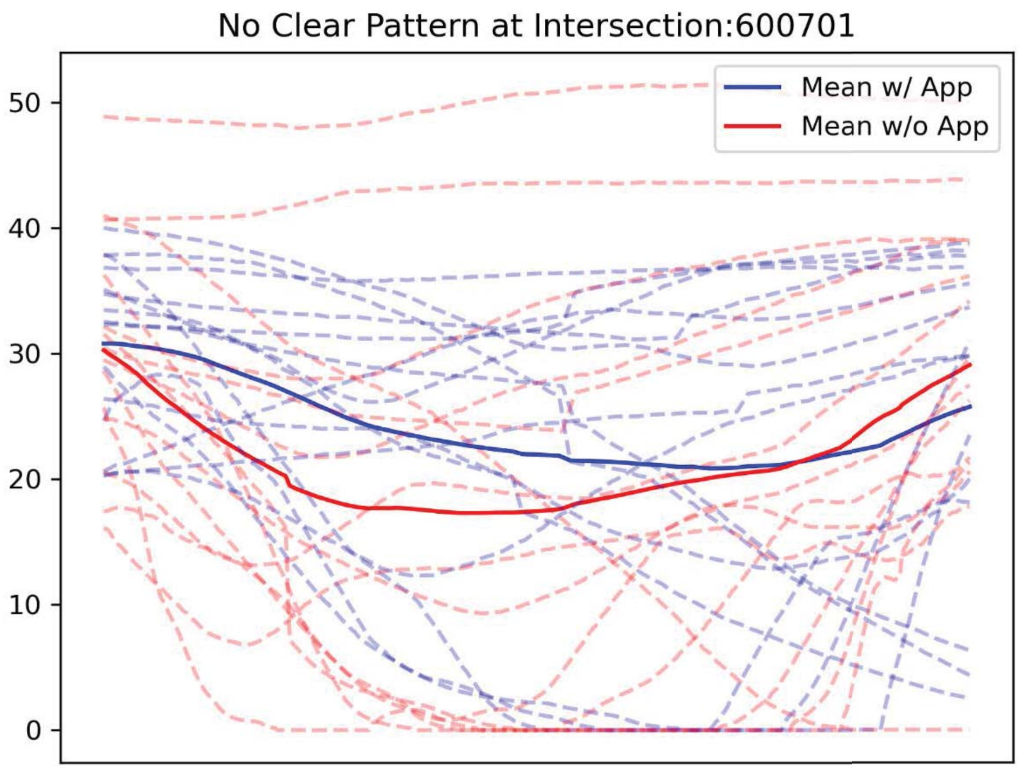

No Clear Pattern at Intersection:100102
Mean w/ App
Mean w/o App
50
40
30
20
10
0

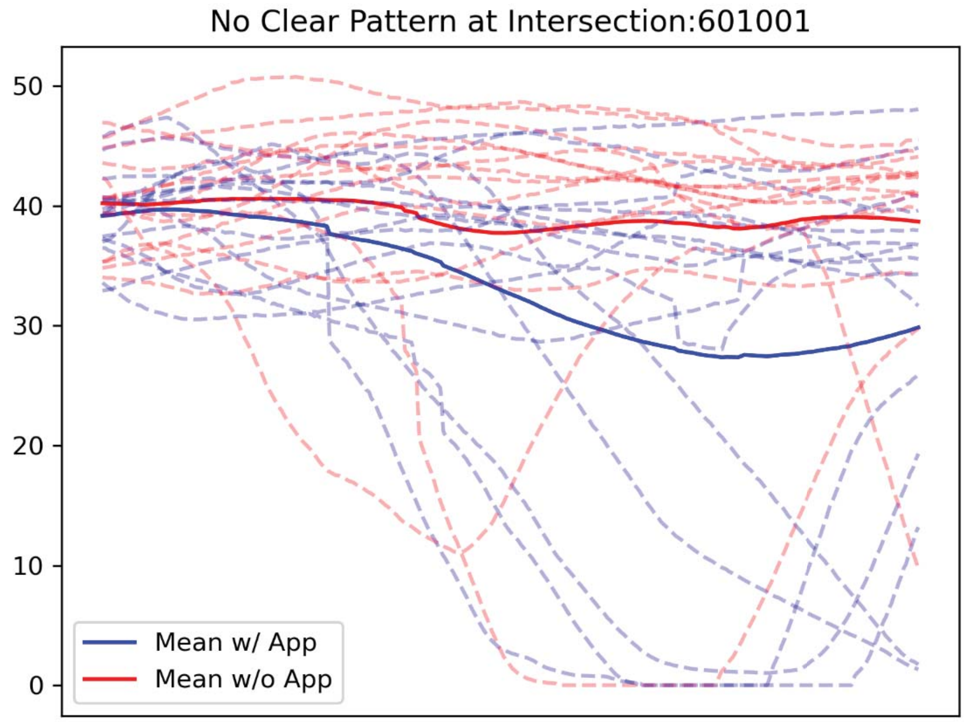

Speed Dip into Rapid Acceleration at Intersection:100202
Mean w/ App
Mean w/o App
35
30
25
20
15
10
5
0

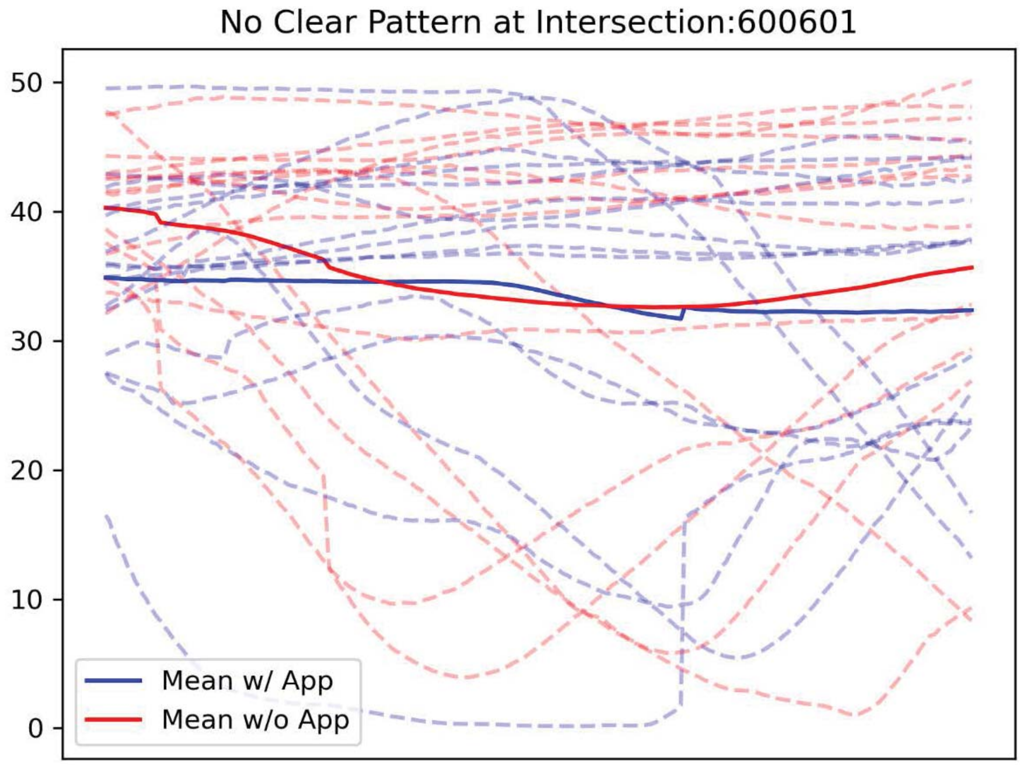

Major Slowdown at Intersection:100104
Mean w/ App
Mean w/o App
40
30
20
10
0

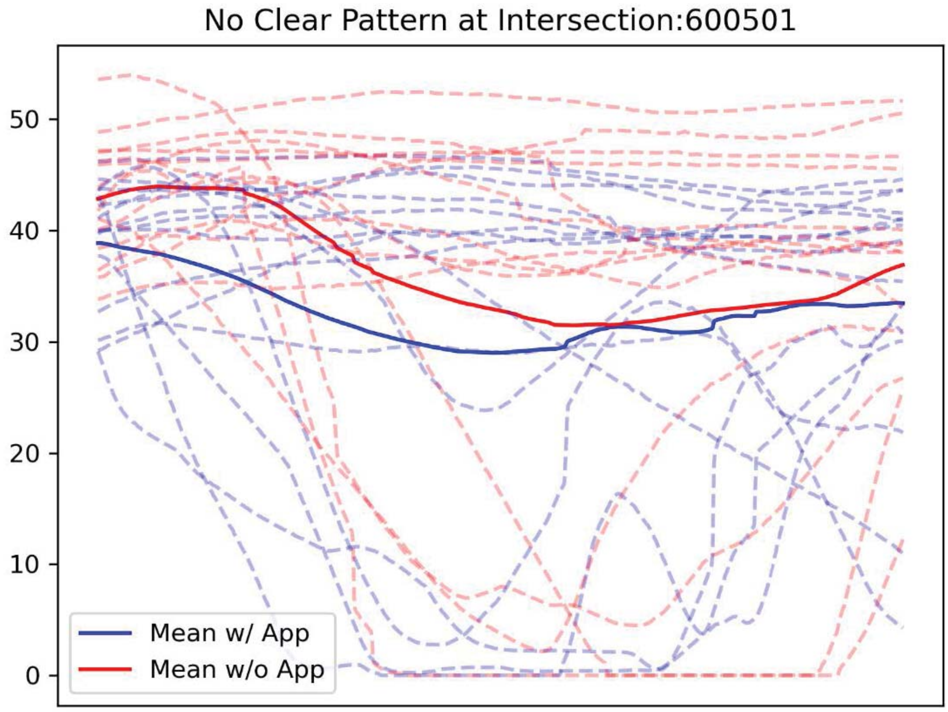

No Clear Pattern at Intersection:600801
50
40
30
20
10
0
Mean w/ App
Mean w/o App

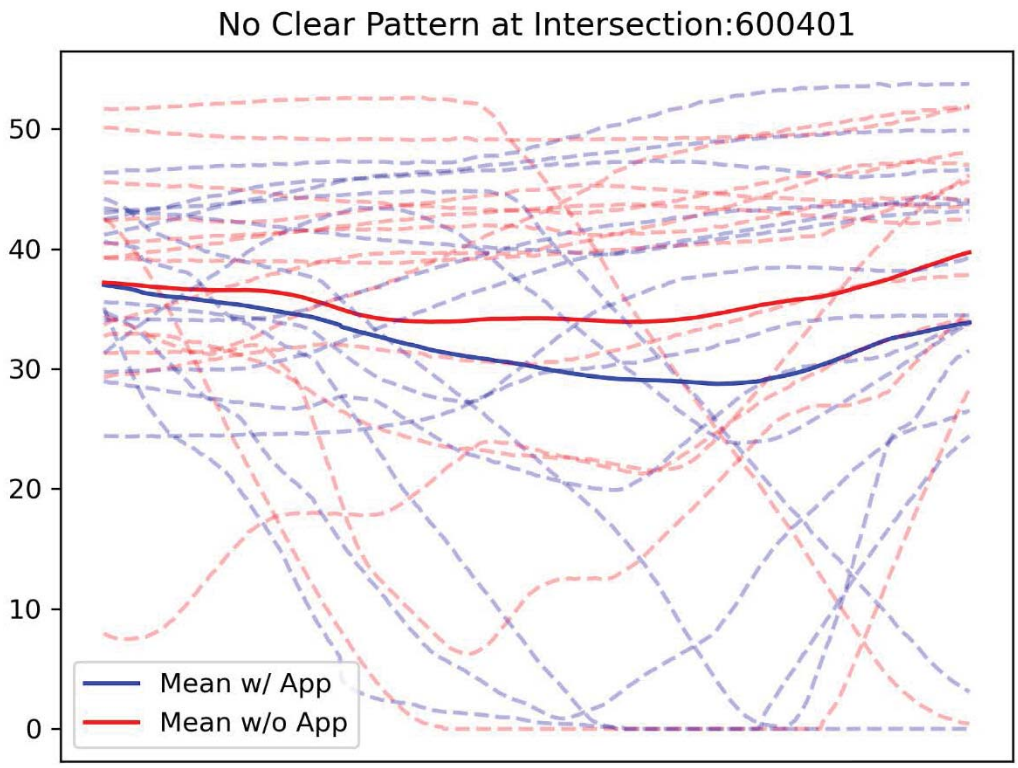

No Clear Pattern at Intersection:601201
50
40
30
20
10
0
Mean w/ App
Mean w/o App

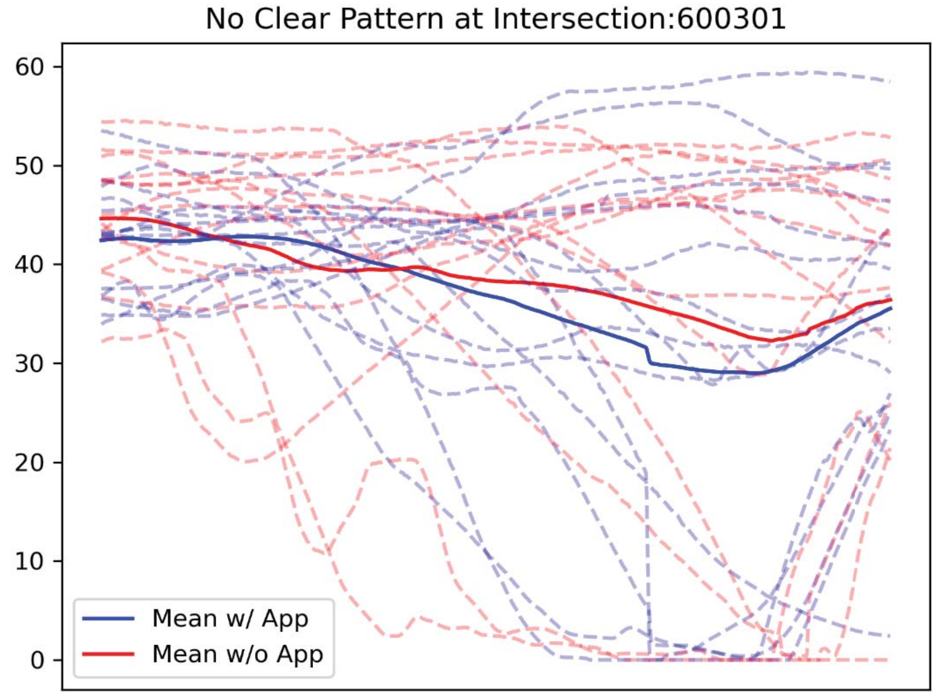

No Clear Pattern at Intersection:600701
50
40
30
20
10
0
Mean w/ App
Mean w/o App

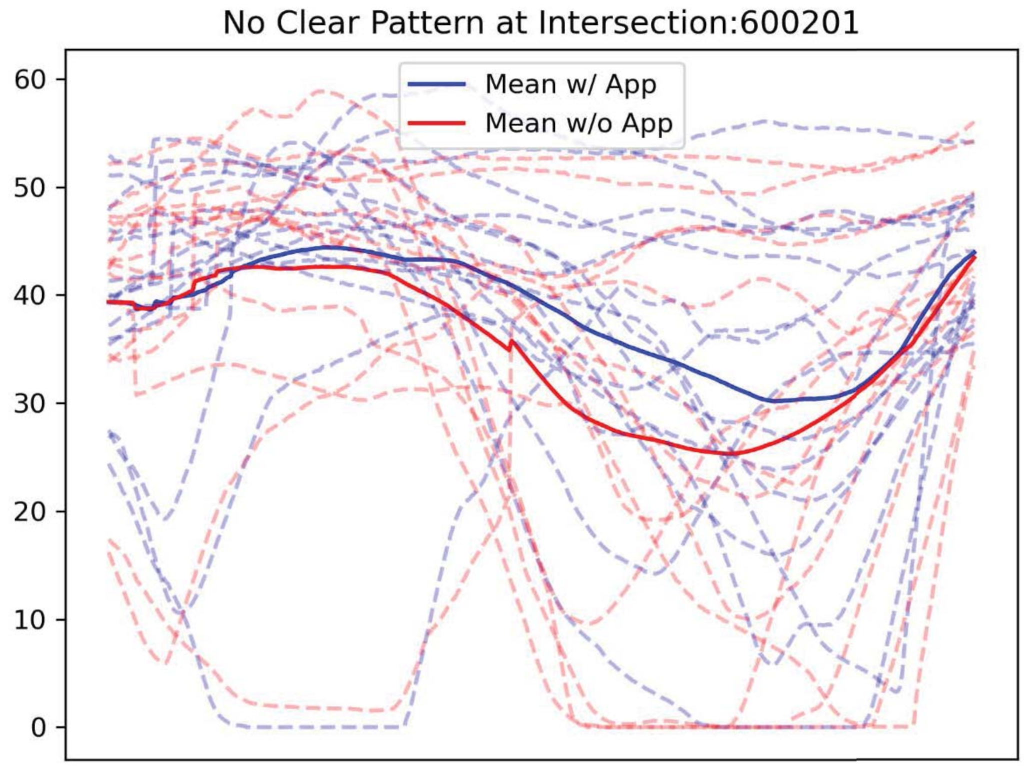

No Clear Pattern at Intersection:601001
50
40
30
20
10
0
Mean w/ App
Mean w/o App

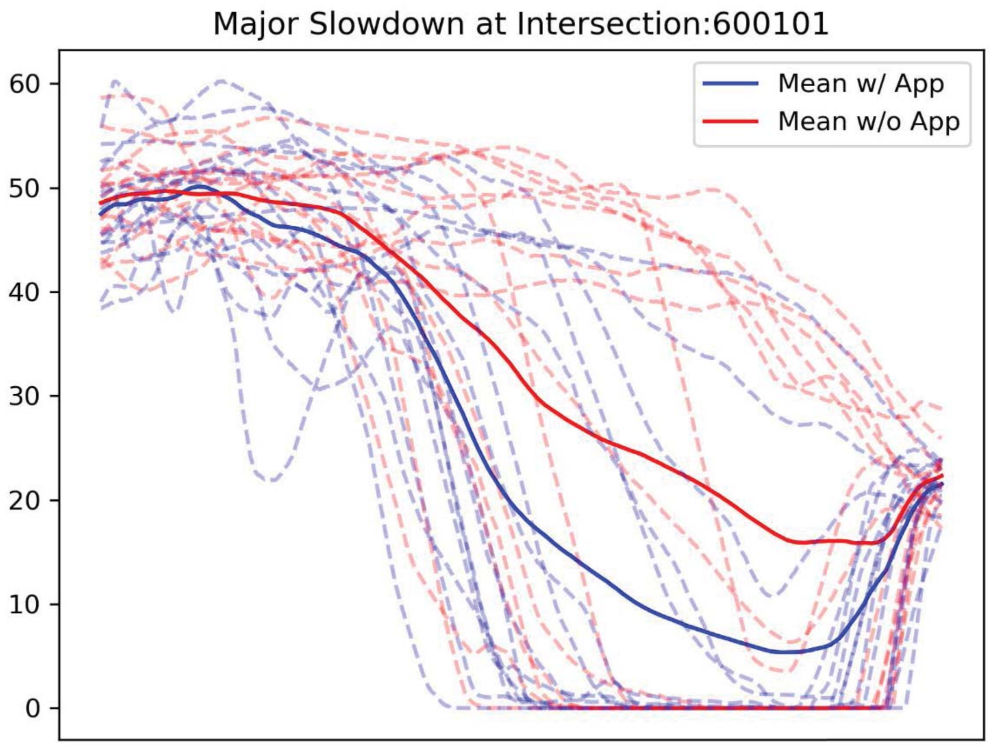

No Clear Pattern at Intersection:600601
50
40
30
20
10
0
Mean w/ App
Mean w/o App


No Clear Pattern at Intersection:600501
50
40
30
20
10
0
Mean w/ App
Mean w/o App

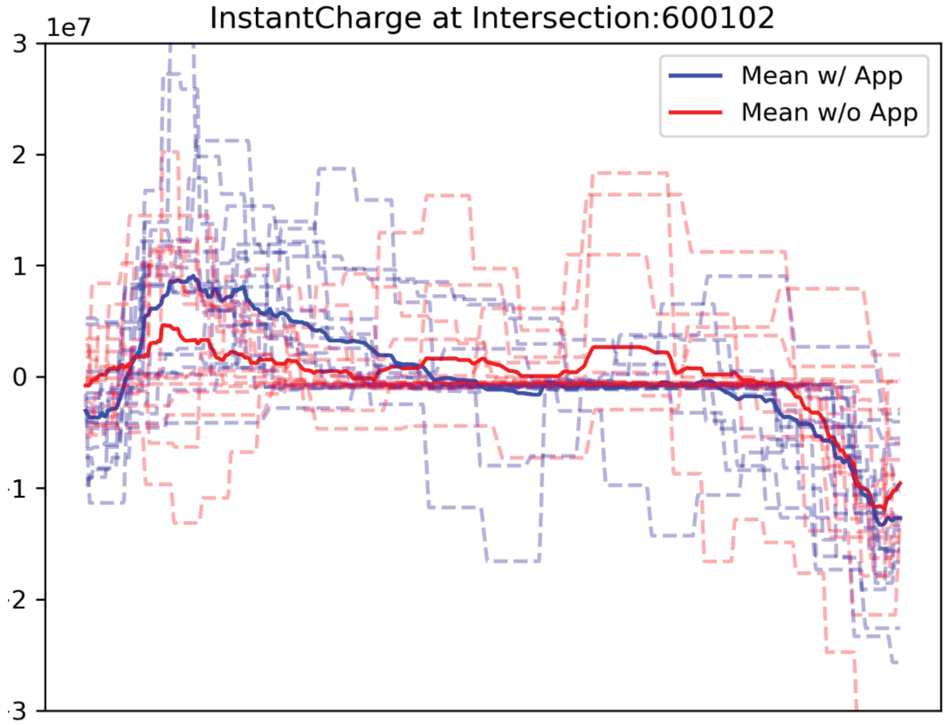

No Clear Pattern at Intersection:600401
50
40
30
20
10
0
Mean w/ App
Mean w/o App

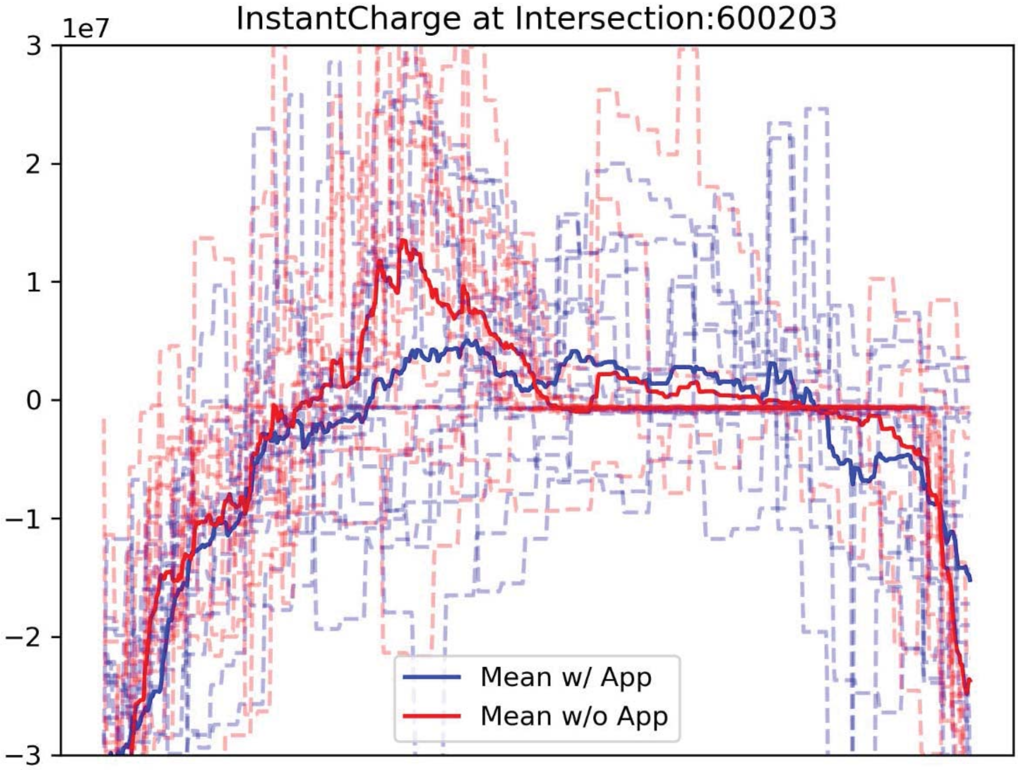

No Clear Pattern at Intersection:600301
60
50
40
30
20
10
0
Mean w/ App
Mean w/o App

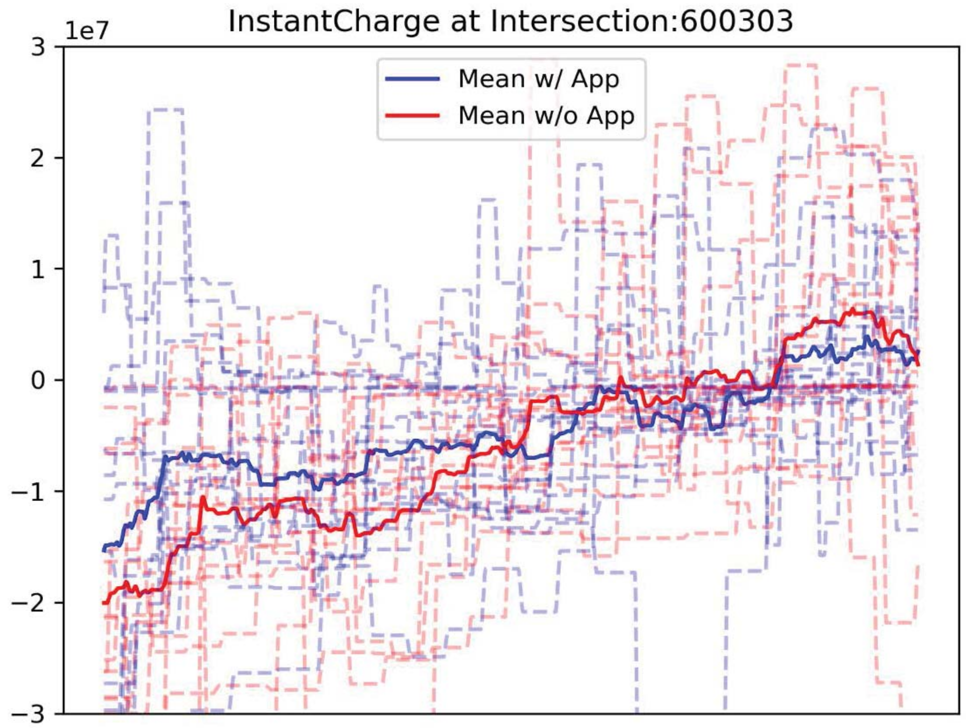

No Clear Pattern at Intersection:600201
60
50
40
30
20
10
0
Mean w/ App
Mean w/o App

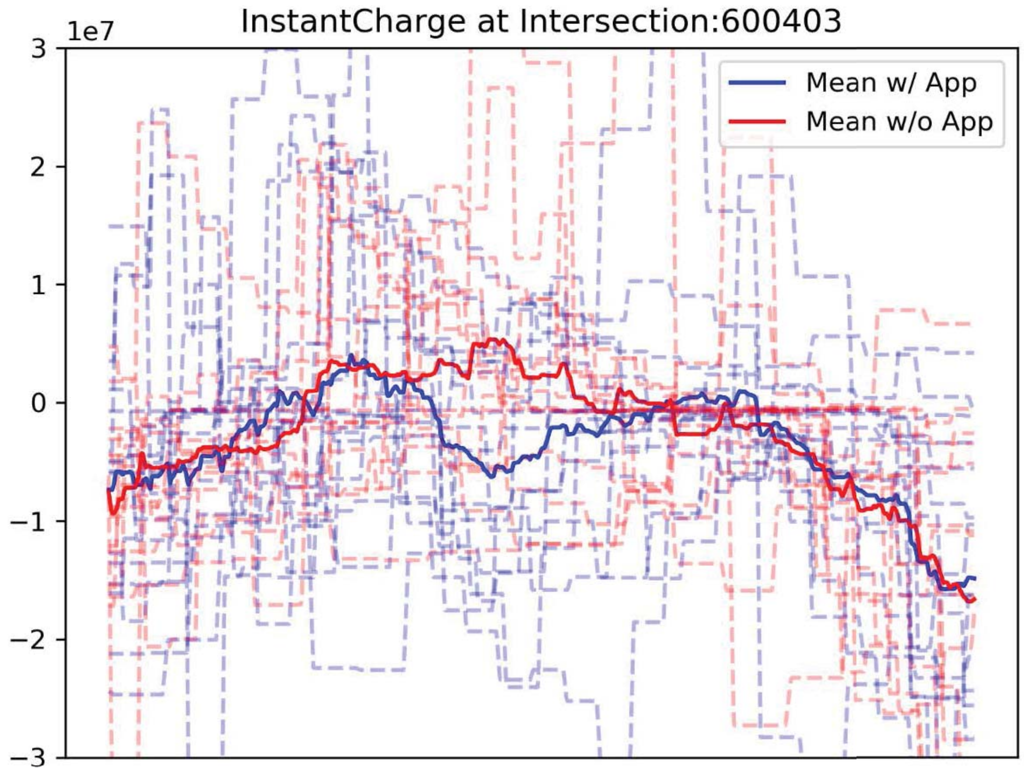

Major Slowdown at Intersection:600101
60
50
40
30
20
10
0
Mean w/ App
Mean w/o App

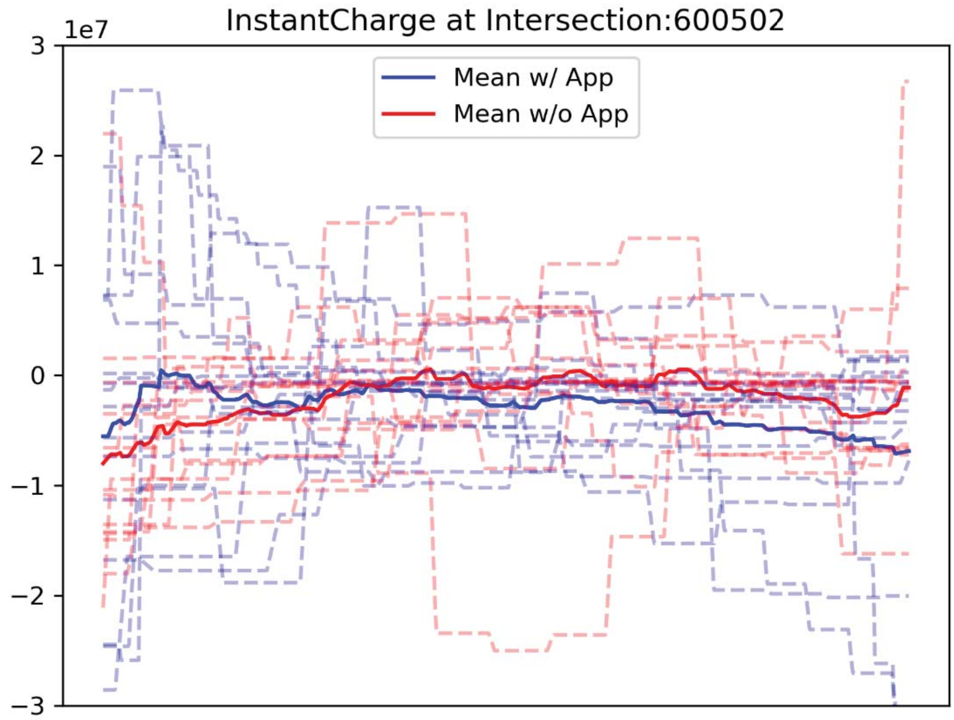
5.2 Average instantCharge patterns for all intersections



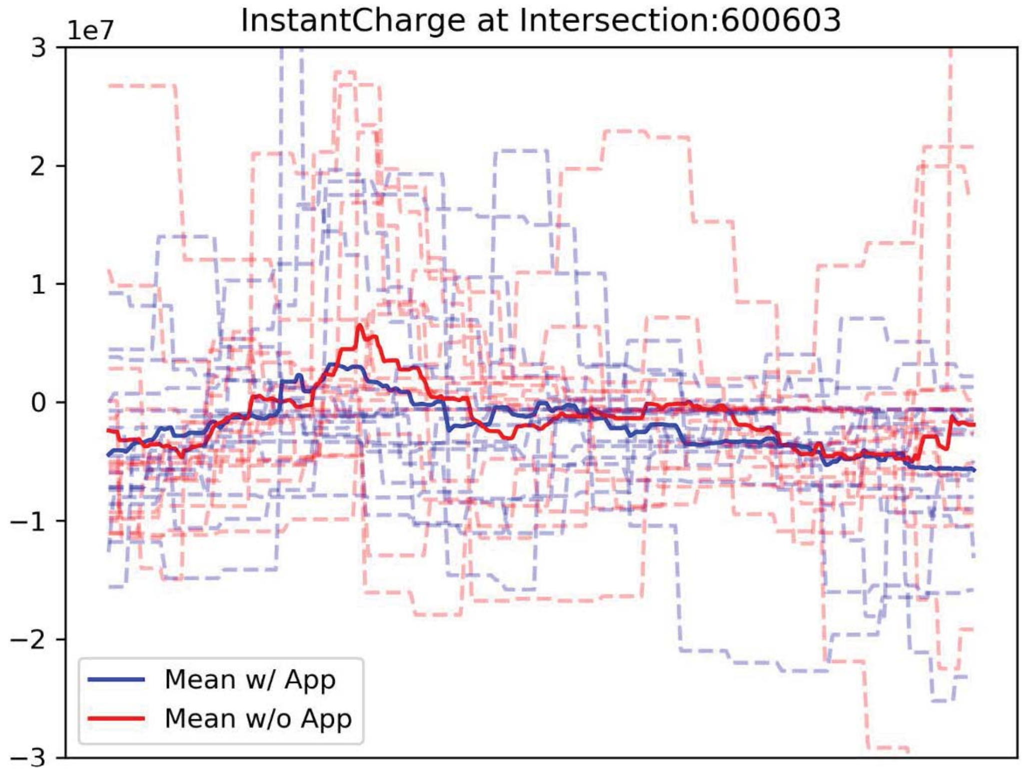



InstantCharge at Intersection:600303
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

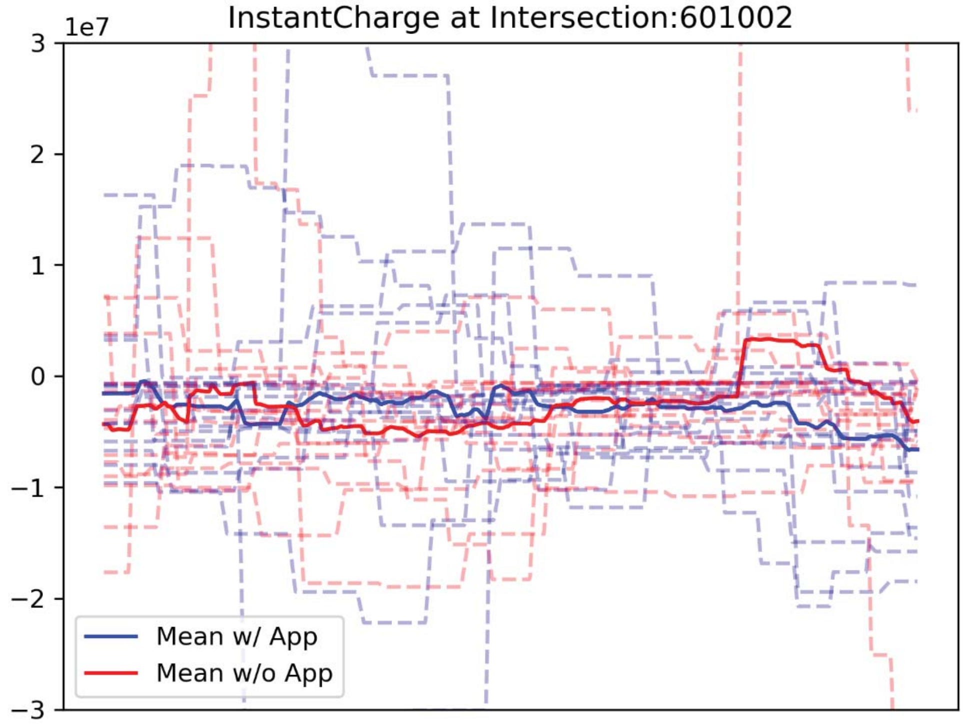

InstantCharge at Intersection:600403
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

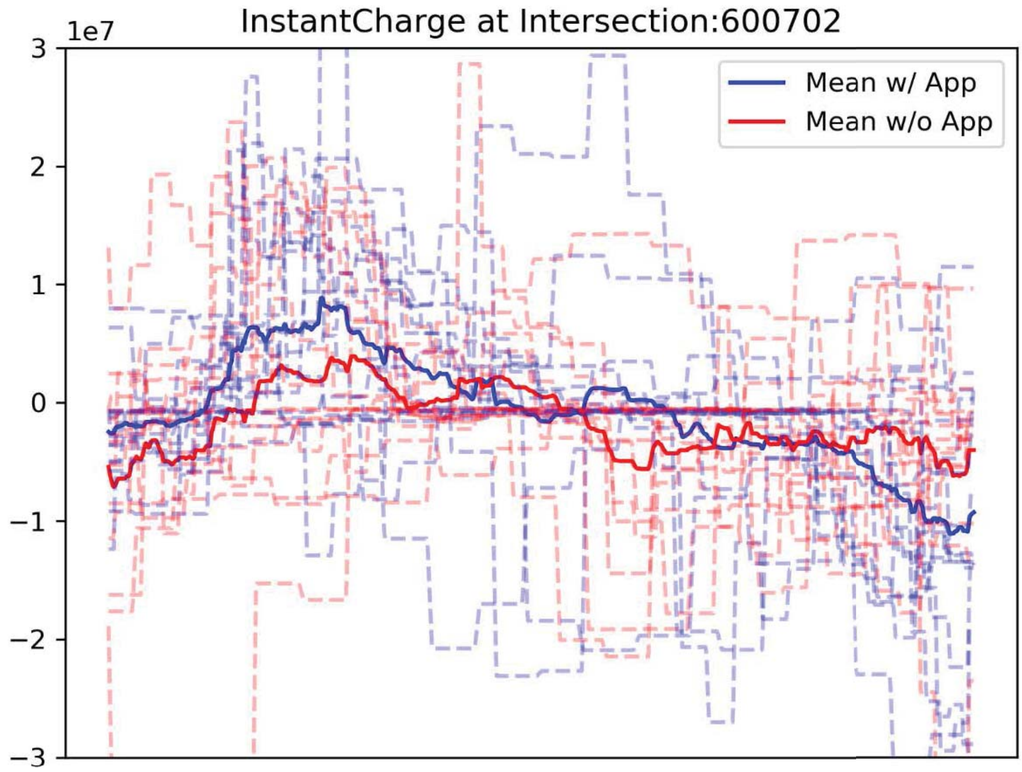


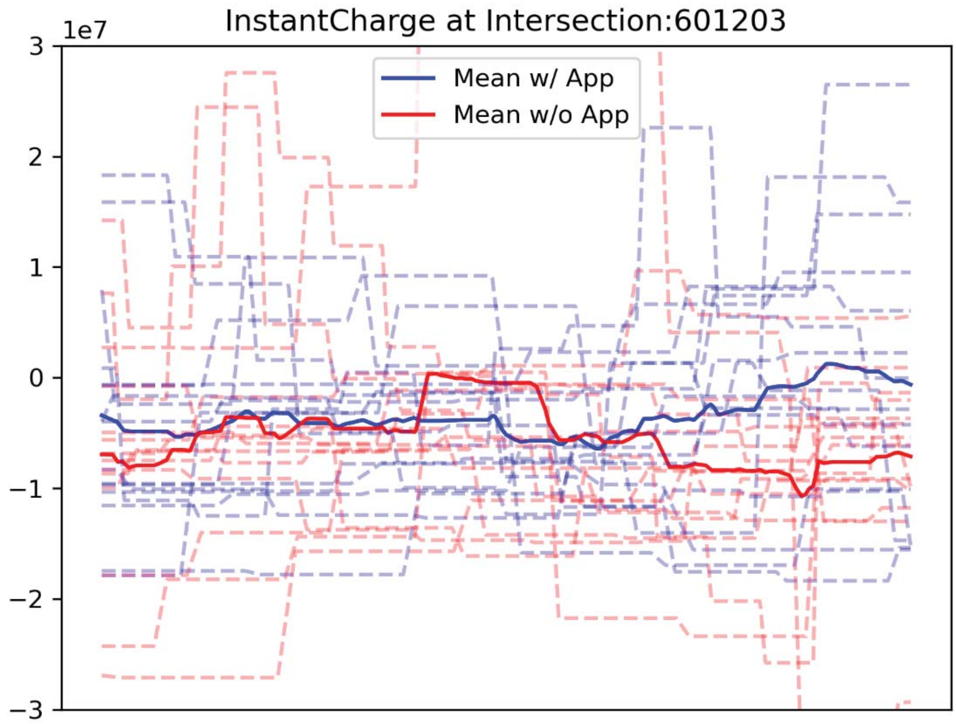
InstantCharge at Intersection:600502
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

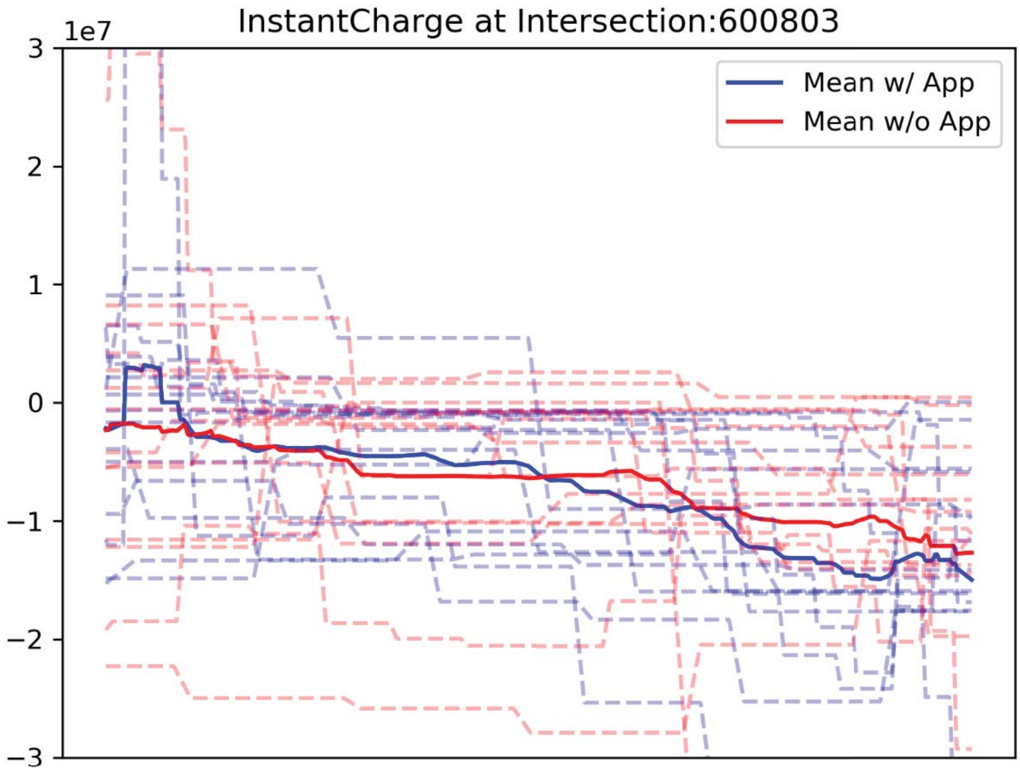


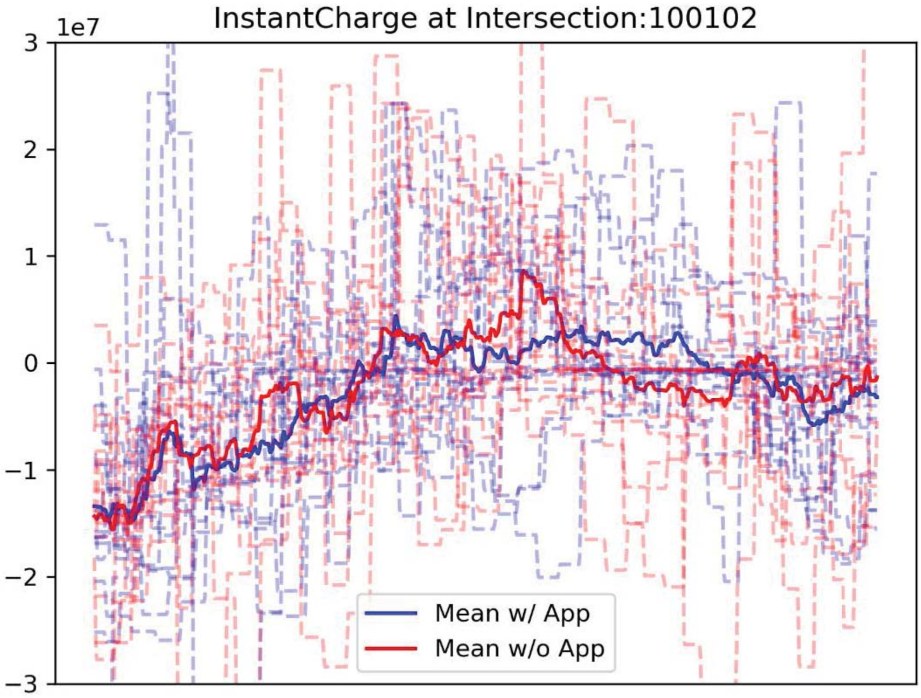
InstantCharge at Intersection:600603
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

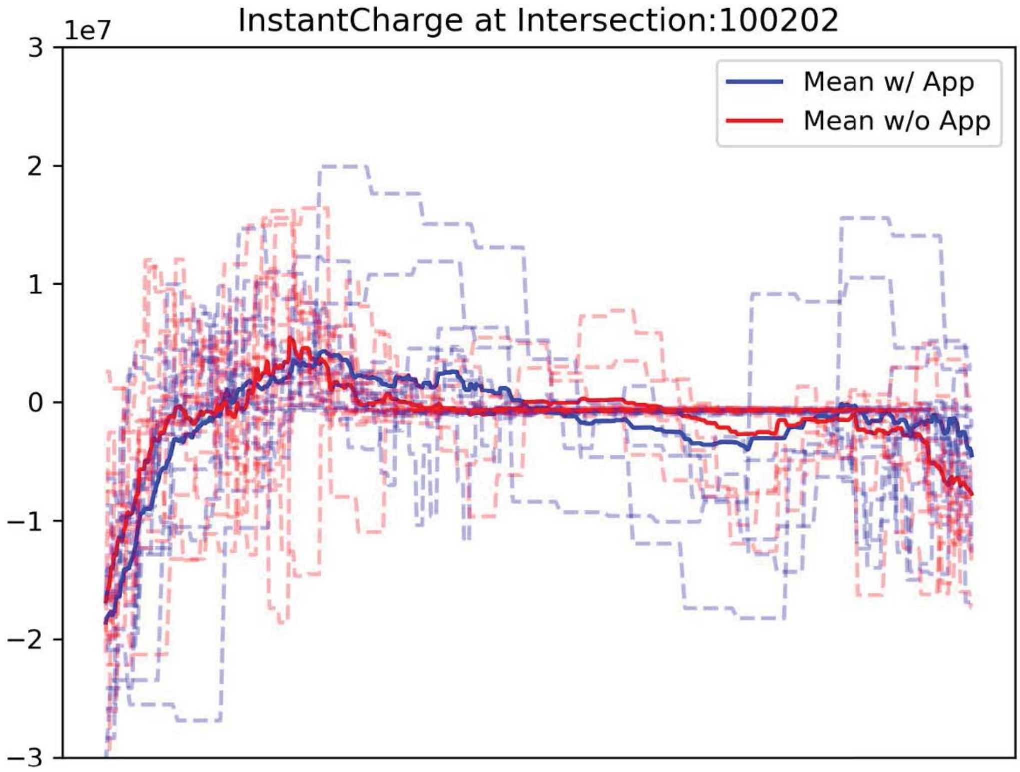

InstantCharge at Intersection:601002
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

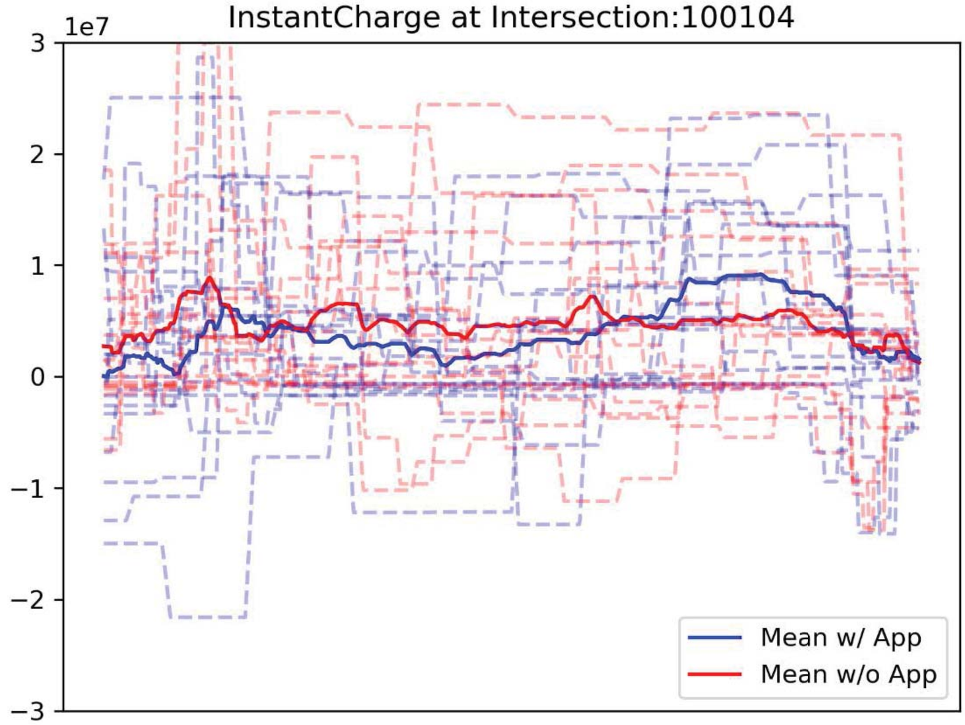

InstantCharge at Intersection:600702
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

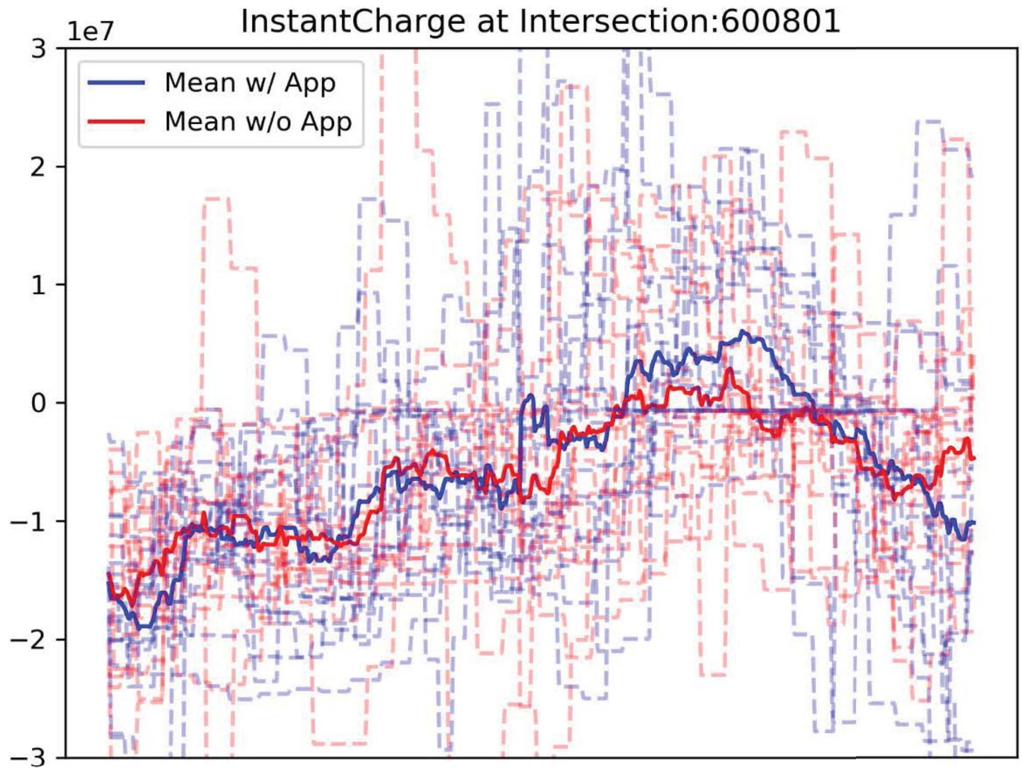

InstantCharge at Intersection:601203
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

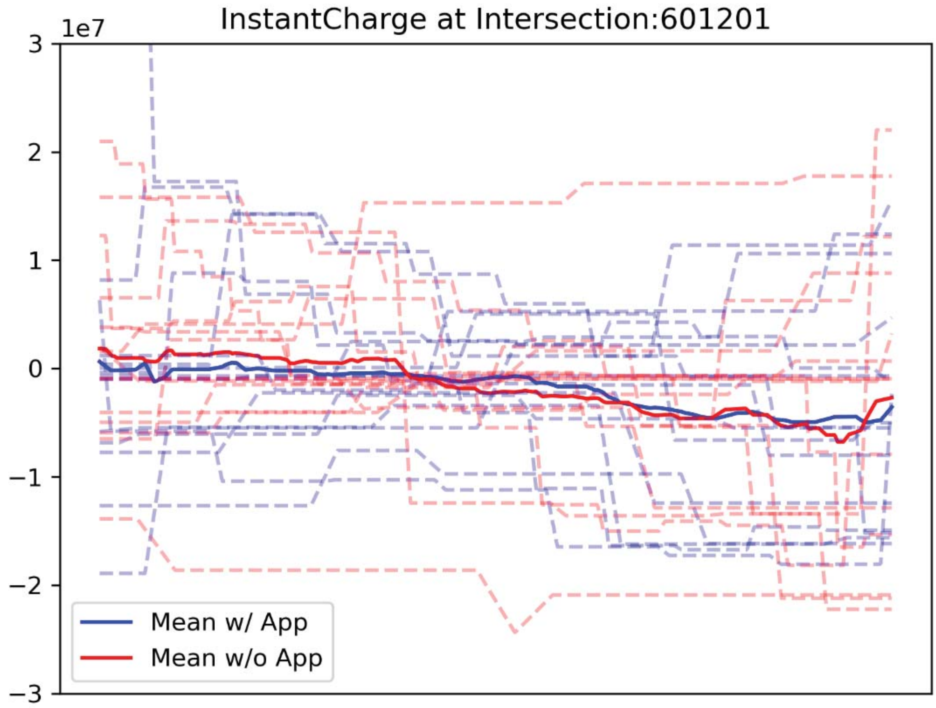

InstantCharge at Intersection:600803
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

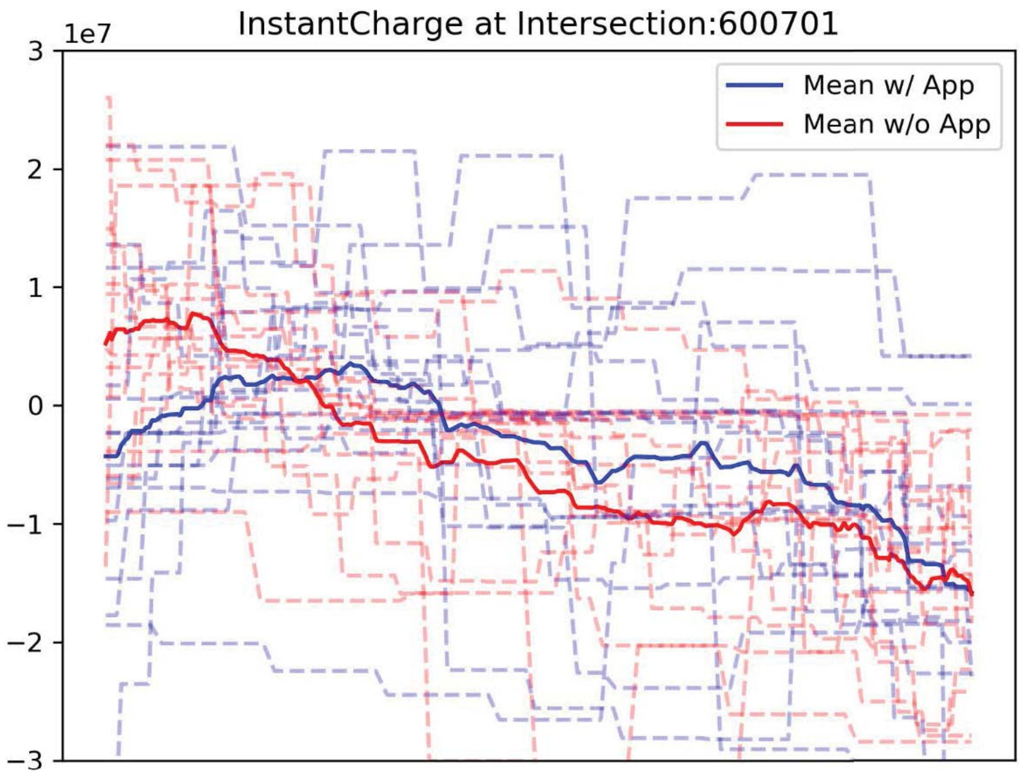

InstantCharge at Intersection:100102
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

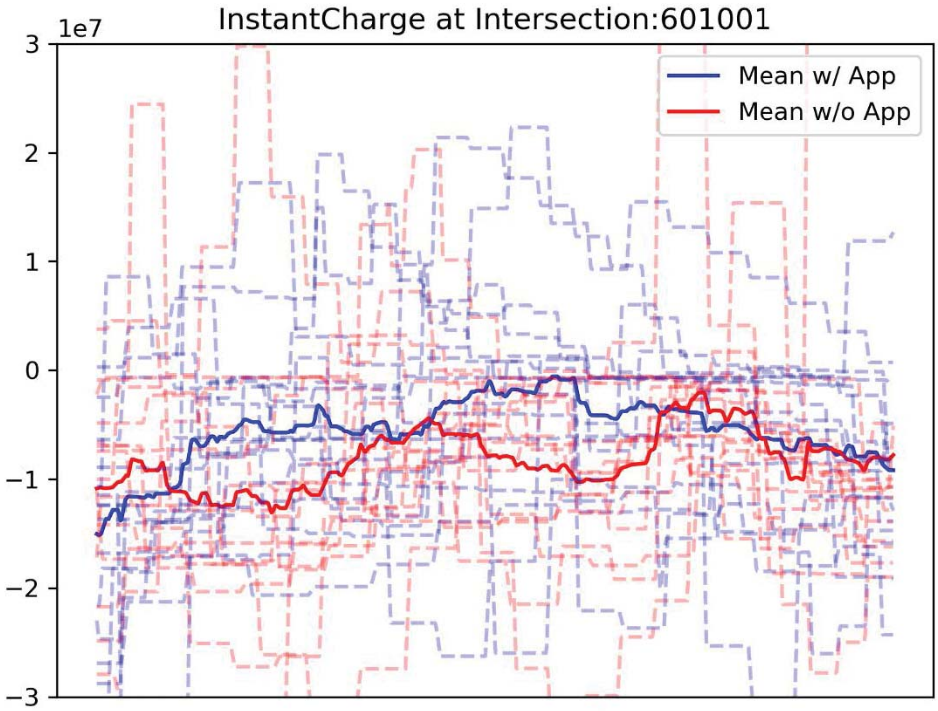

InstantCharge at Intersection:100202
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

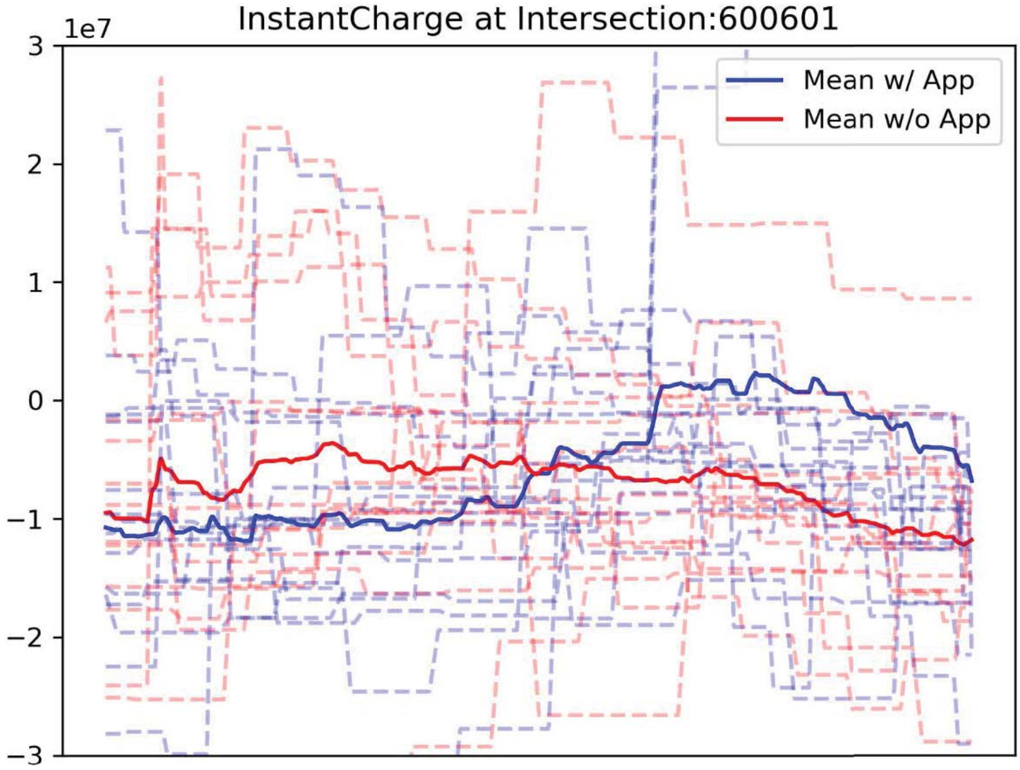

InstantCharge at Intersection:100104
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

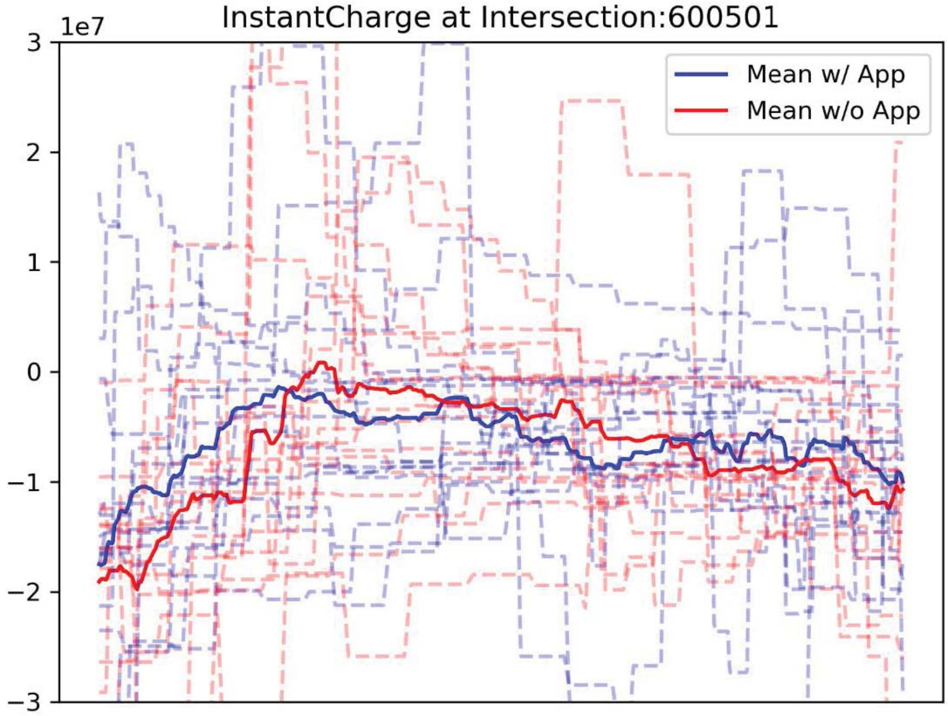

InstantCharge at Intersection:600801
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

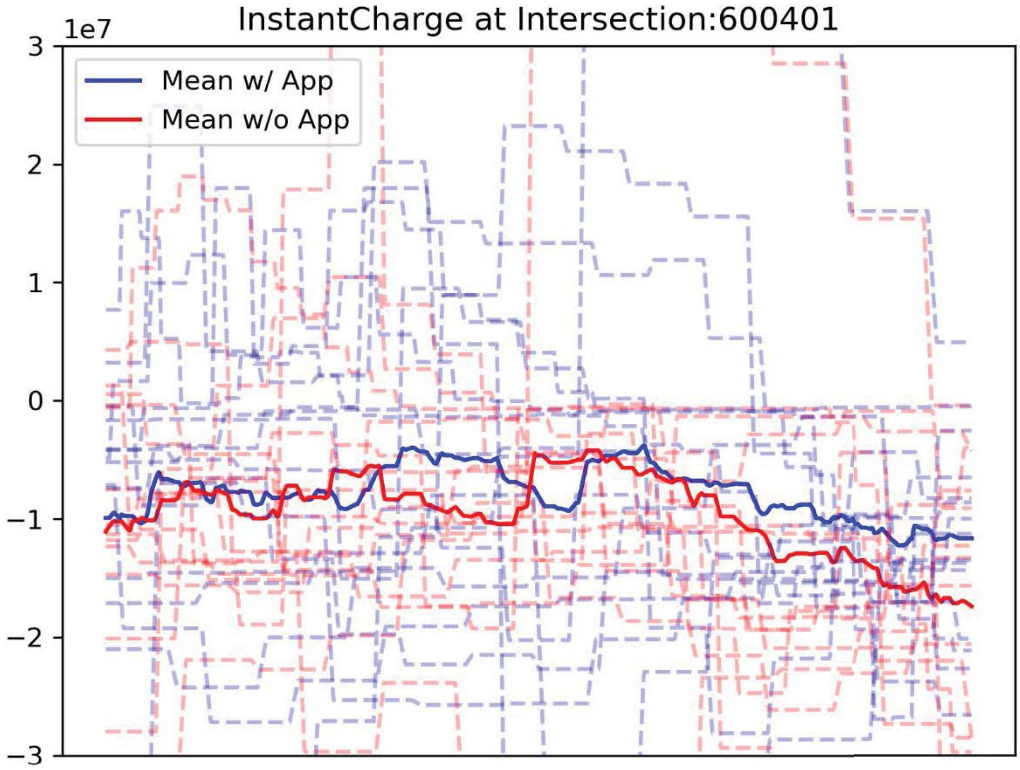

InstantCharge at Intersection:601201
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

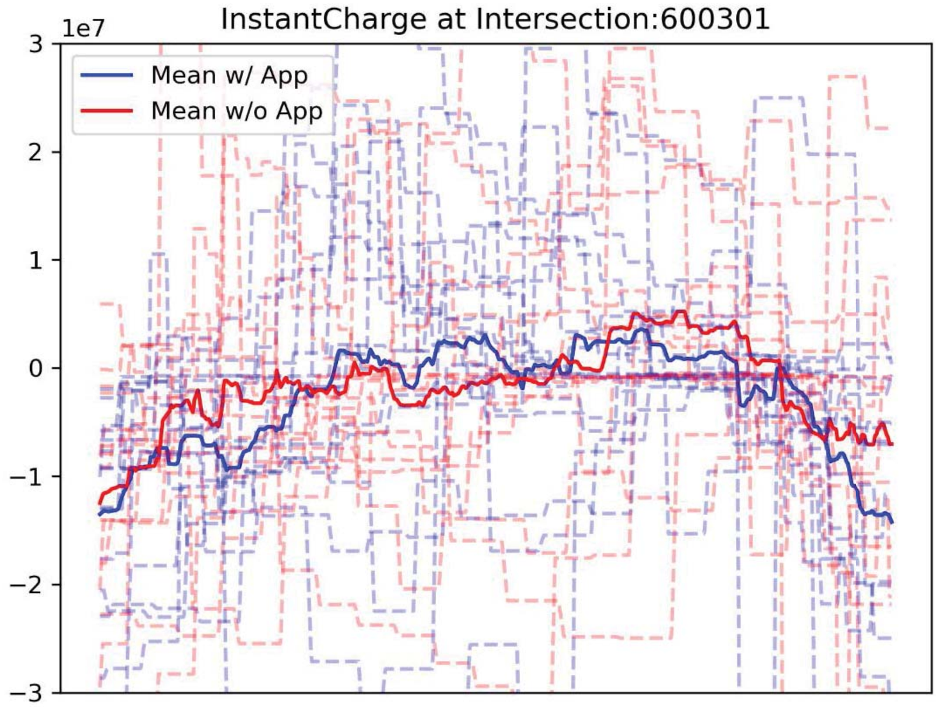

InstantCharge at Intersection:600701
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

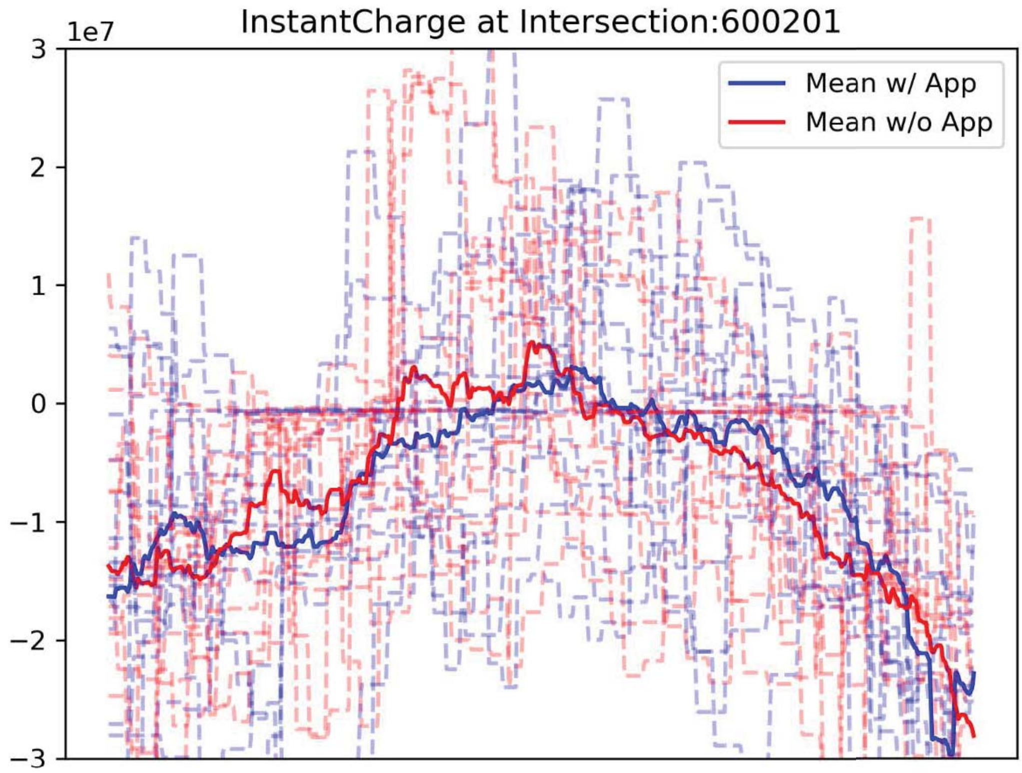

InstantCharge at Intersection:601001
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App

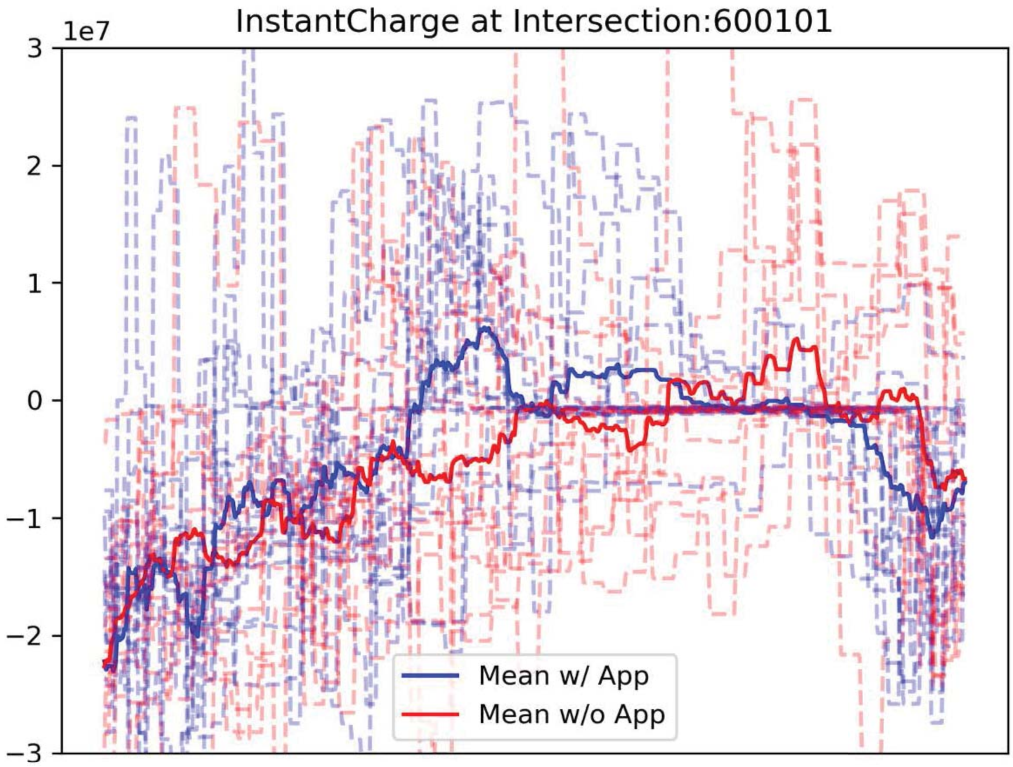

InstantCharge at Intersection:600601
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App


InstantCharge at Intersection:600501
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App


InstantCharge at Intersection:600401
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App


InstantCharge at Intersection:600301
1e7
Mean w/ App
Mean w/o App
3
2
1
0
−1
−2
−3


InstantCharge at Intersection:600201
1e7
Mean w/ App
Mean w/o App
3
2
1
0
−1
−2
−3


InstantCharge at Intersection:600101
1e7
3
2
1
0
−1
−2
−3
Mean w/ App
Mean w/o App