Curb Allocation Change Project

Final Report

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EXECUTIVE SUMMARY

Like many congested cities, Seattle is grappling with how best to manage increasing use of ride-hailing service by Transportation Network Companies (TNCs) like Uber and Lyft. According to a 2018 *Seattle Times* analysis, TNC ridership in the Seattle region has grown to more than five times the level it was in the beginning of 2015, providing, on average, more than 91,000 rides a day in 2018. And the newspaper reports Uber and Lyft trips are heavily concentrated in the city's densest neighborhoods, where nearly 40,000 rides a day start in ZIP codes covering downtown, Belltown, Capitol Hill and South Lake Union.

This University of Washington (UW) study focuses on a strategy to manage TNC driver stops when picking up and dropping off passengers with the aim of improving traffic flow in the South Lake Union (SLU) area. SLU is the site of the main campus for Amazon, the online retail company. The site is known to generate a large number of TNC trips, and Amazon reports high rates of ride-hailing use for employee commutes. This study also found that vehicle picking-up/dropping-off passengers make up a significant share of total vehicle activity in SLU. The center city neighborhood is characterized by multiple construction sites, slow speed limits (25 mph) and heavy vehicle and pedestrian traffic.

Broad concerns about congestion, safety and effective curb use led to this study, conducted by researchers at the UW's Urban Freight Lab and Sustainable Transportation Lab. Amazon specifically was concerned about scarcity of curb space where TNC drivers could legally and readily stop to pick up and drop off passengers. Without dedicated load/unload curb space, TNC vehicles stop and wait at paid parking spots, other unauthorized curb spots, or in the travel lane itself, potentially blocking or slowing traffic. To try to mitigate the impacts of passenger pick-up/drop-off activity on traffic, the city proposed a strategy of increasing passenger loading zone (PLZ) spaces while Uber and Lyft implemented a geofence, which directs their drivers and passengers to designated pick-up and drop-off locations on a block. (Normally, drivers pick up or drop off passengers at any address a rider requests via the ride-hailing app.)

By providing ample designated pick-up and drop-off spots along the curb, the thinking goes, TNC drivers would reduce the frequency with which they stop in the travel lane to pick up or drop off passengers and the time they stay stopped there. By these measures, this study's findings show the approach was successful. But it is important to note that the strategy is not a silver bullet for solving traffic congestion—nor is it designed as such. It is also important to note that any initiative to manage use of curbs and roads (by TNCs or others) is part of a city's broader transportation policy framework and goals.

For this study, researchers analyzed an array of data on street and curb activity along three block-faces on Boren Ave N in December 2018 and January 2019. At a minimum, data were collected during the morning and afternoon peak travel times (with some collected 24 hours a day). The research team collected data using video and sensor technology as well as in-person observation. Researchers also surveyed TNC passengers for demographic, trip-related and satisfaction data. The five Amazon buildings in the area studied house roughly 8,650 employees.

Researchers collected data in three stages. Phase 1, the study baseline, was before PLZs were added and geofencing started. Phase 2 was after the new PLZs were added, expanding total PLZ curb length from 20 feet (easily filled by one to two vehicles) to 274 feet. Phase 3 was after geofencing was added to the expanded PLZs. The added PLZ spaces were open to any passenger vehicle—not just TNC vehicles—weekdays from 7am to 10am and 2pm to 7pm. (Permitted food trucks were authorized from 10am to 2pm.)

Note that while other cities can learn from this analysis, the findings apply to streets with comparable traffic speed, mix of roadway users, and street design.

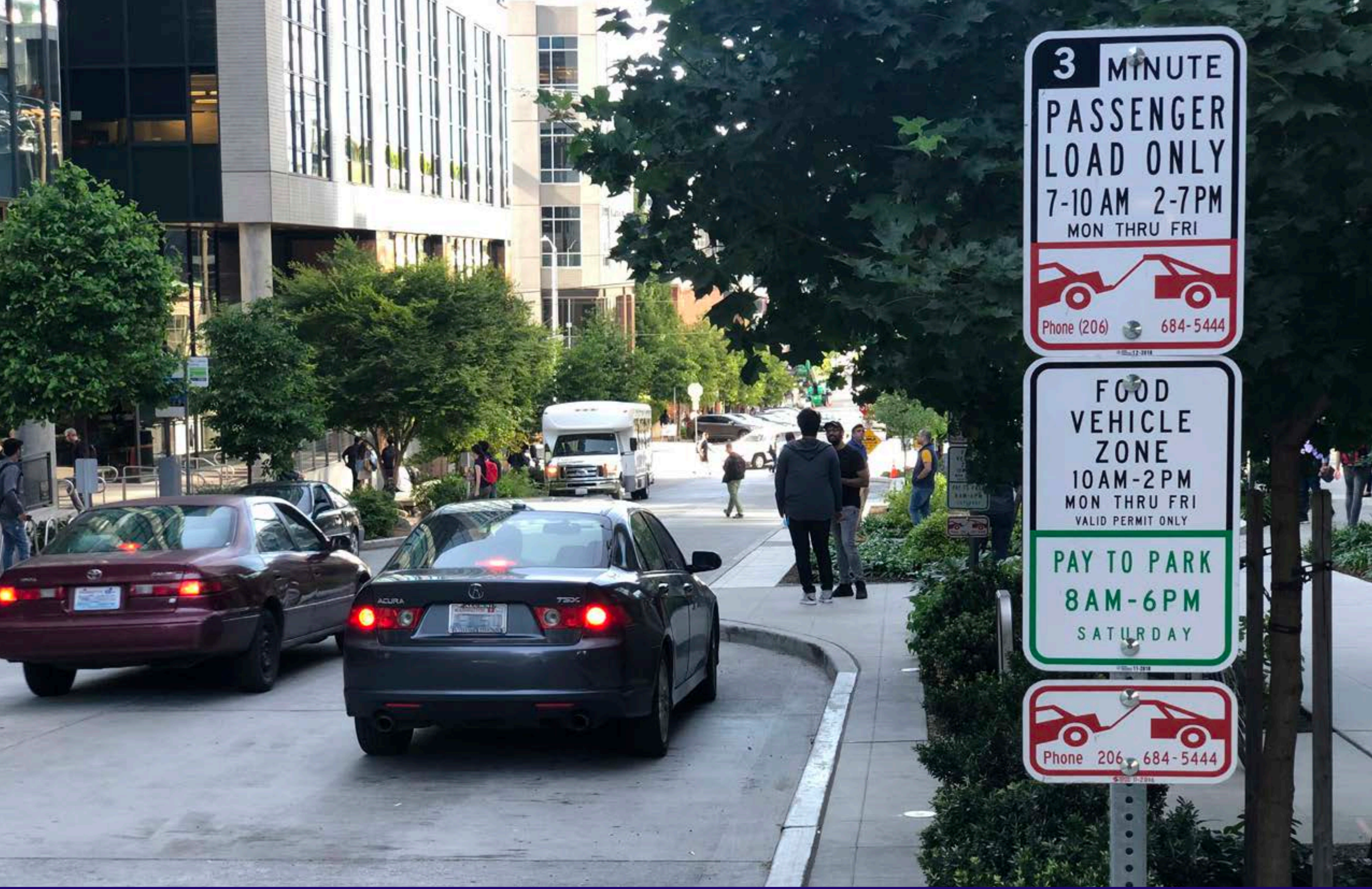
The study's main findings include:

- A significant percentage of vehicles performing a pick-up/drop-off stop in the travel lane. Those in-lane stops appear connected to the lack of available designated curb space: Adding PLZs and geofencing increased driver compliance in stopping at the curb versus stopping in the travel lane to load and unload passengers. But it was not lack of curb space alone that influenced driver activity: Between 7 percent and 10 percent of drivers still stopped in the travel lane even when PLZs were empty. After adding PLZs and geofencing, in-lane stops fell from 20 percent to 14 percent for pick-ups and from 16 percent to 15 percent for drop-offs.
- Adding PLZs and geofencing reduced the average amount of time drivers stopped to load and unload passengers. For example, 90 percent of drop-offs took less than 1 minute 12 seconds, 42 seconds faster than the average with the added PLZs alone.
- While curb occupancy increased after adding PLZs and geofencing, occupancy results show the current allocation of PLZ spaces is more than what is needed to meet observed demand: Average PLZ occupancy remained under 20 percent after PLZ expansion, even during peak commute hours.
- Vehicles picking-up/dropping-off passengers account for a significant share of total traffic volume in the study area: during peak hours the observed average percentage of vehicles performing a pick-up/drop-off with respect to the total traffic volume was 29 percent (in Phase 1), 32 percent (in Phase 2) and 39 percent (in Phase 3).
- High volumes of pedestrians (400-500 per hour on average) cross the street at points where there was no crosswalk. Passengers picked-up/dropped-off constituted a fraction (five to seven percent) of those pedestrians, but high rates of passengers (30 to 40 percent) cross the street at non-crosswalk locations.
- Adding PLZs and geofencing did not have a significant impact on traffic safety. Researchers found no significant change in the number of observed conflicts from baseline to the addition of PLZs and geofencing. Conflicts are situations where a vehicle, bike, or pedestrian is interrupted, forced to alter their path, or engaged in a near-miss situation. Conflicts include vehicles passing in the oncoming traffic lane.
- Adding PLZs and geofencing also did not produce a significant impact on roadway travel speed.
- Of the 116 TNC passengers surveyed in the study area:
    - Roughly 40 percent to 50 percent said their trip was work related. More than half said they used ride-hailing service at least once a week and 70 percent or more used TNC alone (versus in combination with other transportation options) to get from their origin to their destination.
    - Most responded positively to the added PLZs and geofence: 79 percent rated their pick-up satisfactory and 100 percent rated their drop-off satisfactory as compared to 72 percent and 89 percent in the baseline.
    - Nearly half said they would have taken transit and one-third would have walked if ride-hailing was not available.
    - 40 percent requested a shared TNC vehicle in Phase 1 and 47 percent in Phase 3.

The study suggests that while vehicles picking-up/dropping-off passengers account for a significant share of traffic volume in SLU, they are not the primary cause of congestion. Myriad factors impact neighborhood congestion, including high vehicle volume overall and bottlenecks moving out of the neighborhood onto regional arterials. As researchers observed in the afternoon peak, these bottlenecks cause spillbacks onto local streets. Amazon garages exit vehicles onto streets that then feed into these clogged arterials.

Regarding traffic safety in SLU, this study was not designed to assess whether TNC driver behavior on average is safer or less safe than that of other vehicles. It is important to understand the safety and speed findings in the context of the SLU traffic environment. Drivers tend to drive at relatively slow speeds, navigating around high pedestrian and jaywalking volumes, and seem relatively comfortable stopping in the middle of the street for short periods of time. Due to the nature of area traffic, this seems to have relatively little impact on other drivers. Drivers appear to anticipate both this behavior and the high volumes of vehicles moving onto/off the curb and into/out of driveways and alleys.

Whether the strategy this study analyzed is recommended depends on a city's transportation goals and approach. The researchers found the increased PLZ allocation and geofencing strategy worked in that it improved driver compliance, reduced dwell times, and boosted TNC user satisfaction. However, this may encourage commuters to use TNC. The passenger survey clearly shows that TNC service is attracting passengers who would have otherwise walked or used transit. While in the short term the increased PLZs and geofencing had a positive effect on traffic, if this induces TNC demand, there could be larger, more negative long-term consequences. If the end goal is to reduce traffic congestion, measures to reduce—rather than encourage—TNC and passenger car use as the predominant mode of commuting will yield the most substantial benefits.



1

Introduction

1 INTRODUCTION

In recent years, many U.S. cities have seen a rapid increase in ride-hailing trips by Transportation Network Companies (TNCs), such as Uber and Lyft. By providing application dispatch services, TNCs allow travelers to connect with drivers via smartphone apps. Nationally, the share of Americans who have used ride-hailing services has more than doubled since 2015, from 15 percent to 36 percent.

According to an analysis by The *Seattle TImes*, TNC ridership in the Seattle region has grown to more than five times the level it was in the beginning of 2015, providing, on average, more than 91,000 rides a day in 2018. Those rides were equivalent to roughly one-quarter of the city's public transit ridership at the time. Additionally, Uber and Lyft trips are heavily concentrated in the city's densest neighborhoods, where nearly 40,000 rides a day start in ZIP codes covering downtown, Belltown, Capitol Hill and South Lake Union.

This study focuses on a strategy to manage TNC driver stops when picking up and dropping off passengers with the aim of improving traffic flow in the South Lake Union (SLU) neighborhood, the site of the main campus for Amazon, the online retail company. Amazon reports high rates of ride-hailing use for employee commutes, and this analysis found vehicles picking-up/dropping-off passengers constitute on average between 29% to 39% of total traffic volume in SLU, during peak hours. The center city neighborhood is characterized by multiple construction sites, slow speed limits (25 mph) and heavy vehicle and pedestrian traffic.

Unless dedicated spaces are reserved for pick-up and drop-off activities (referred to as Passenger Load Zone, or PLZ, spaces), TNC vehicles stop and wait at spaces allocated for other purposes (such as paid parking spots or other unauthorized curb spaces) or in the travel lane itself, potentially blocking or slowing traffic and adding to congestion. Rising TNC use poses challenges for how cities can best manage curb space in the context of their broader transportation initiatives and goals. In Seattle, some have called for the city to consider allocating more city curb space for passenger pick-up and drop-off.

Broad concerns about congestion, safety and effective curb use led to this study, conducted by researchers at the University of Washington's Urban Freight Lab and Sustainable Transportation Lab. Amazon specifically was concerned about a scarcity of curb space for TNCs to stop to pick up and drop off riders. To try to mitigate the impacts of TNC vehicles on traffic, the city proposed a strategy of increasing passenger loading zone (PLZ) spaces while Uber and Lyft implemented a geofence, which directs their drivers and passengers to designated pick-up and drop-off spots on a block (Normally, drivers pick up or drop off passengers at any address a rider requests via the ride-hailing app).

The rationale behind the two-pronged strategy posits that by providing ample designated pick-up and drop-off spots along the curb, TNC drivers would reduce the frequency with which they stop in the travel lane to pick up or drop off passengers and the time they stay stopped there. By these measures, the findings show the approach was successful.

Adding PLZs and geofencing did increase TNC driver compliance in stopping at the curb versus stopping in the travel lane to load and unload passengers: In-lane stops for pick-ups fell from 20 percent at baseline to 14 percent and for drop-offs fell from 16 percent at baseline to 15 percent. That said, it was not lack of curb space alone that influenced TNC driver activities: Between 7 percent and 10 percent of drivers still stopped in the travel lane even when PLZ spaces were empty.

Adding PLZs and geofencing did reduce the average amount of time TNC drivers stopped to load and unload passengers: 90 percent of drop-offs took less than 1 minute 12 seconds, 42 seconds faster than the average with the added PLZs alone.

These findings aside, it is critical to note that the strategy is not a silver bullet for solving traffic congestion—nor is it designed as such.

For this study, researchers analyzed an array of data on street and curb activity along three block-faces on Boren Ave N in December 2018 and January 2019. At a minimum, data were collected during the morning and afternoon peak travel times (with some collected 24 hours a day). The research team collected data using video and sensor technology as well as in-person observation. The five Amazon buildings in the area studied house roughly 8,650 employees. Researchers also surveyed TNC passengers for an array of demographic and TNC use data.

Data was collected in three stages. Phase 1, the study baseline, was before PLZs were added and geofencing started. Phase 2 was after the new PLZs were added, expanding total PLZ curb length from 20 feet (easily filled by one to two vehicles) to 274 feet. Phase 3 was after geofencing was added to the expanded PLZs. The PLZ spaces were open to any passenger vehicle—not just TNC vehicles. (The exception was the hours from 10am to 2pm, when spots were reserved for permitted food trucks.)

This research examines the impact of the increased PLZs and geofencing on local traffic and TNC operation by asking the extent to which:

- TNC dwell time changed
- It was easier or harder for TNC passengers and drivers to find each other
- TNC drivers' compliance changed in using curb space for passenger pick-up and drop-off versus stopping in the travel lane
- TNC drivers' decision to stop in the travel lane is a consequence of curb availability
- Study area traffic speed changed
- Study area traffic safety changed
- The added PLZs were utilized

The study also investigates:

- How TNC passenger satisfaction changed in response to the strategy
- TNC share of total traffic volume in the study area

It is worth noting that while other cities can learn from this analysis, the findings apply to streets with comparable traffic speed, mix of roadway users, and street design.

2

Study Area

2 STUDY AREA

This study has been conducted in the South Lake Union (SLU) area of Seattle, WA (Figure 1). There are a number of Amazon buildings located in this area, and Amazon reports high rates of ride-hailing use for employee commutes. The area is also known as a busy area in terms of vehicular traffic, pedestrian activity, and passenger pick-up/drop-offs.

Over the course of this study, the Seattle Department of Transportation (SDOT) made changes to PLZs and paid parking zones in the area with the intent of influencing traffic flow. The curb change area is shown in Figure 2 and covers south of Mercer St, west of Fairview Ave, north of John St and east of 9th Ave N. The changes include a) installing signs to reduce the paid parking time limit and to change curb allocation from paid parking/food truck (PS-VEN) to passenger load zone/food truck (PLZ-VEN), and b) geofencing for pick-up/drop-off activities.

Figure 1: South Lake Union (SLU) area in Seattle, WA

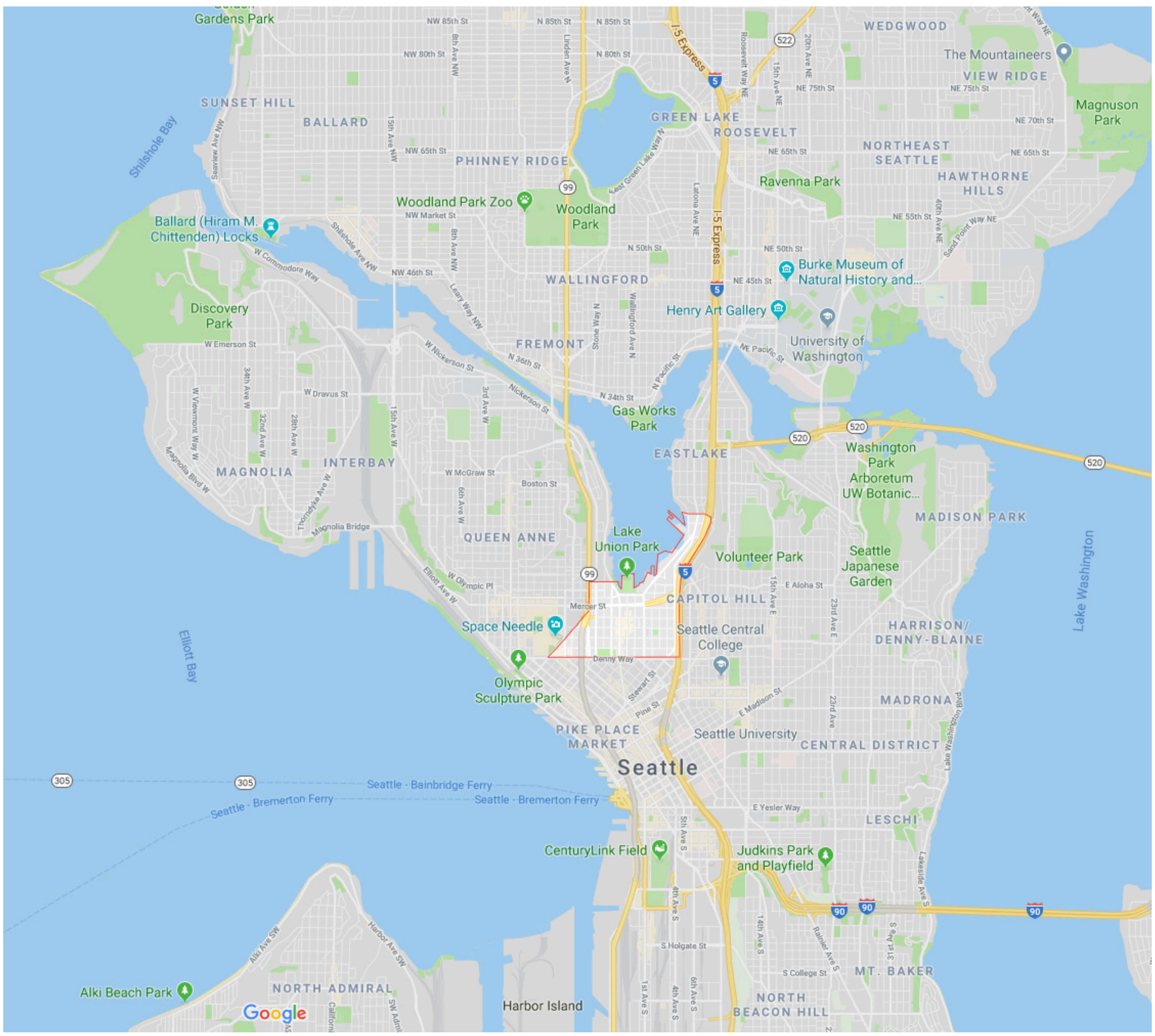
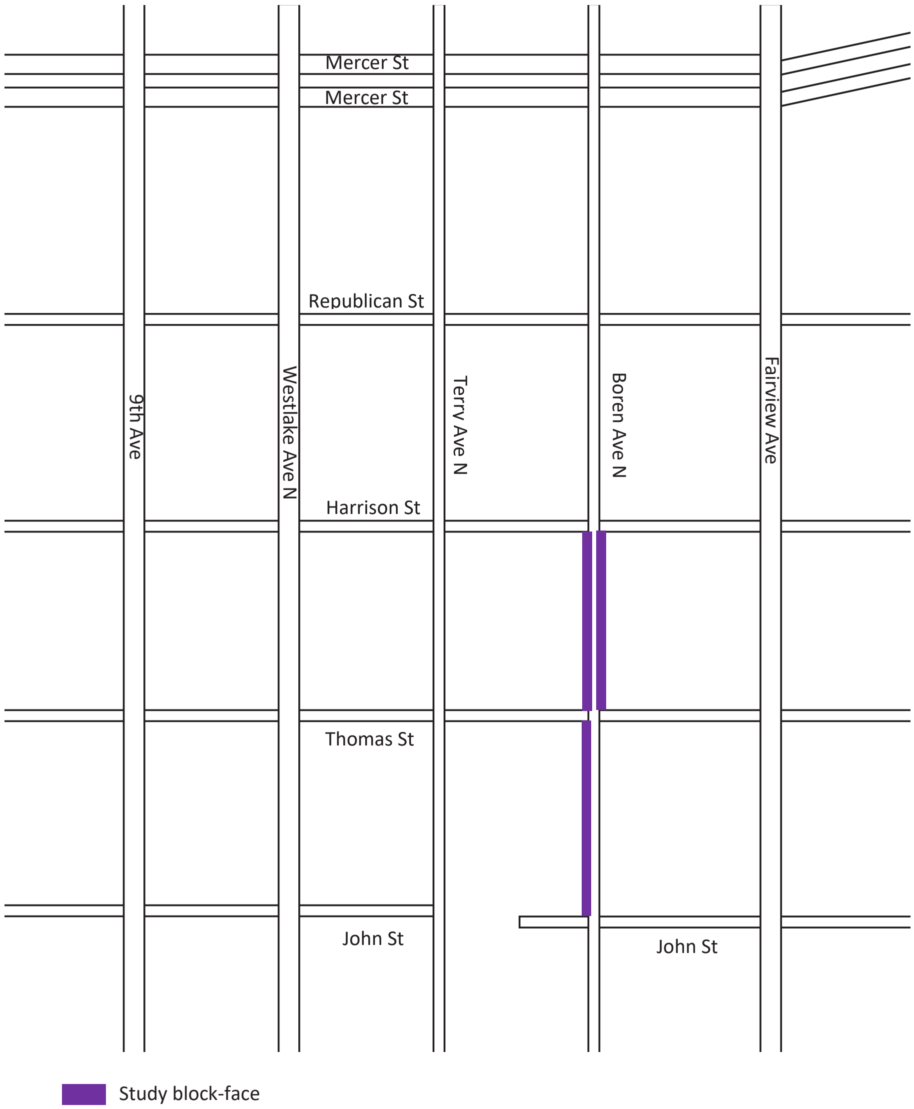


Figure 2: Curb change area and study block-faces



Curb reallocation and sign installation happened on December 10, 2018, and the new PLZs were effective 7-10am and 2-7pm Monday through Friday (Figure 3). Permitted food trucks were authorized to use the curb between 10am-2pm on weekdays. This resulted in an increase in PLZ spaces, which are the curb allocation intended for use by TNC vehicles or other vehicles picking up or dropping off passengers. A complete inventory of changes along with detailed maps are provided in Appendix A.

Figure 3: Signs installed by SDOT for the added PLZs

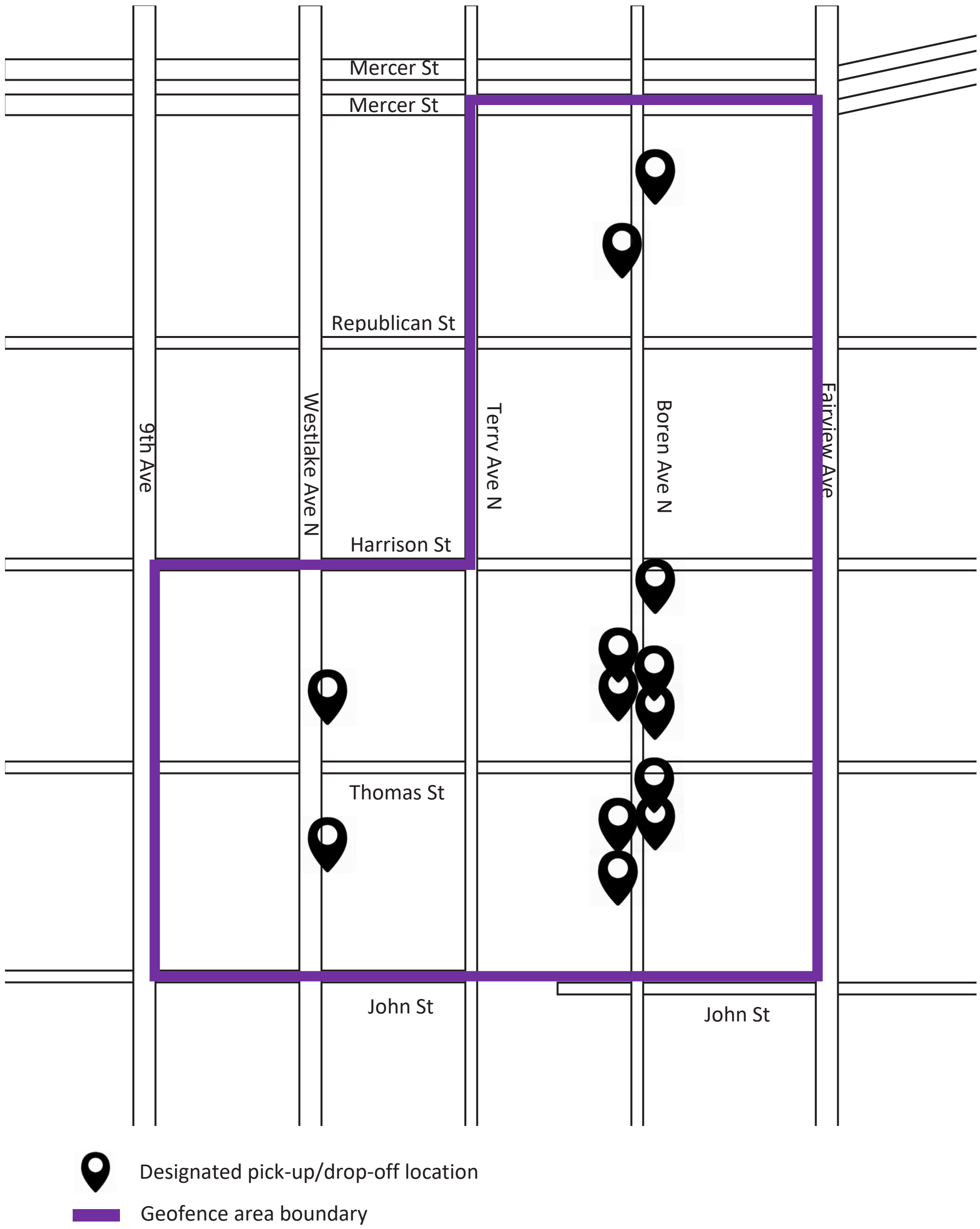
In addition to curb reallocations, two ride-hailing companies, Uber and Lyft, implemented a geofence in the area for passenger pick-ups and drop-offs. Implemented in the Uber and Lyft applications, geofencing directed ride-hailing drivers and passengers to designated locations along a block with the purpose of regulating TNC vehicle operations. Geofencing was implemented on December 24, 2018, and the pick-up/drop-off points implemented in the ride-hailing apps are shown in Figure 4. It should be noted that Uber applied geofencing all day, while Lyft limited it to 7-10 am and 2-7 pm to match the signs.

For this project, we selected three block-faces on Boren Ave N to study more closely. The study block-faces are shown in Figure 2 and listed below:

- East side of Boren between Harrison and Thomas Streets
- West side of Boren between Harrison and Thomas Streets
- West side of Boren between Thomas and John Streets

Total PLZ curb length on these block-faces was expanded from 20 feet (easily filled by one to two vehicles) to 274 feet. These block-faces experience intense pick-up and drop-off activity, as well as high pedestrian volumes, during peak hours, and there are one or two Amazon buildings on each block-face. The number of employees seated at the five Amazon buildings next to our study block-faces was about 8,650 at the time of

Figure 4: Geofence area and designated pick-up/drop-off locations implemented in SLU



study. It is worth noting that Amazon informed its employees of the geofencing and the designated pick-up/drop-off locations via sending out an email announcement and posting flyers on December 24th, 2018 (the go-live date for geofencing). A copy of the flyer shared with employees is provided in Appendix B.

3

Data

3 DATA

Data collection was conducted in three phases, as explained in Table 1. In each phase, five week-days of data were collected. Phase 1 data was collected from the 3rd to the 7th of December 2018, and is referred to as the Baseline as no changes had been implemented yet. Phase 2 data was collected from the 17th to the 21st of December 2018, after the curb changes took place and new parking signs were permanently installed. Phase 3 data was collected from the 7th to the 11th of January 2019, after Uber and Lyft geofenced the area for passenger pick-up and drop-off (the curb change signs stayed during Phase 3). The data collection was timed to be completed before the closure of the Alaskan Way viaduct, a major arterial road in Seattle, which took place on the 12th of January 2019." The collected data elements are explained in the following subsections.

Table 1: Three phases of data collection

PHASE	DESCRIPTION	DATES
1: Baseline	Control phase (No changes)	12/3/2018 to 12/7/2018
2: Added PLZs	Signs were installed to change paid parking to PLZ at AM and PM times.	12/17/2018 to 12/21/2018
3: Added PLZs + Geofence	Curb change signs stayed, and TNCs Geofenced up.	1/7/2019 to 1/11/2019

3.1 Curb Activity Data

This data was collected by IDAX Data Solutions through capturing video and coding the video data into quantitative measures. The quantitative measures include:

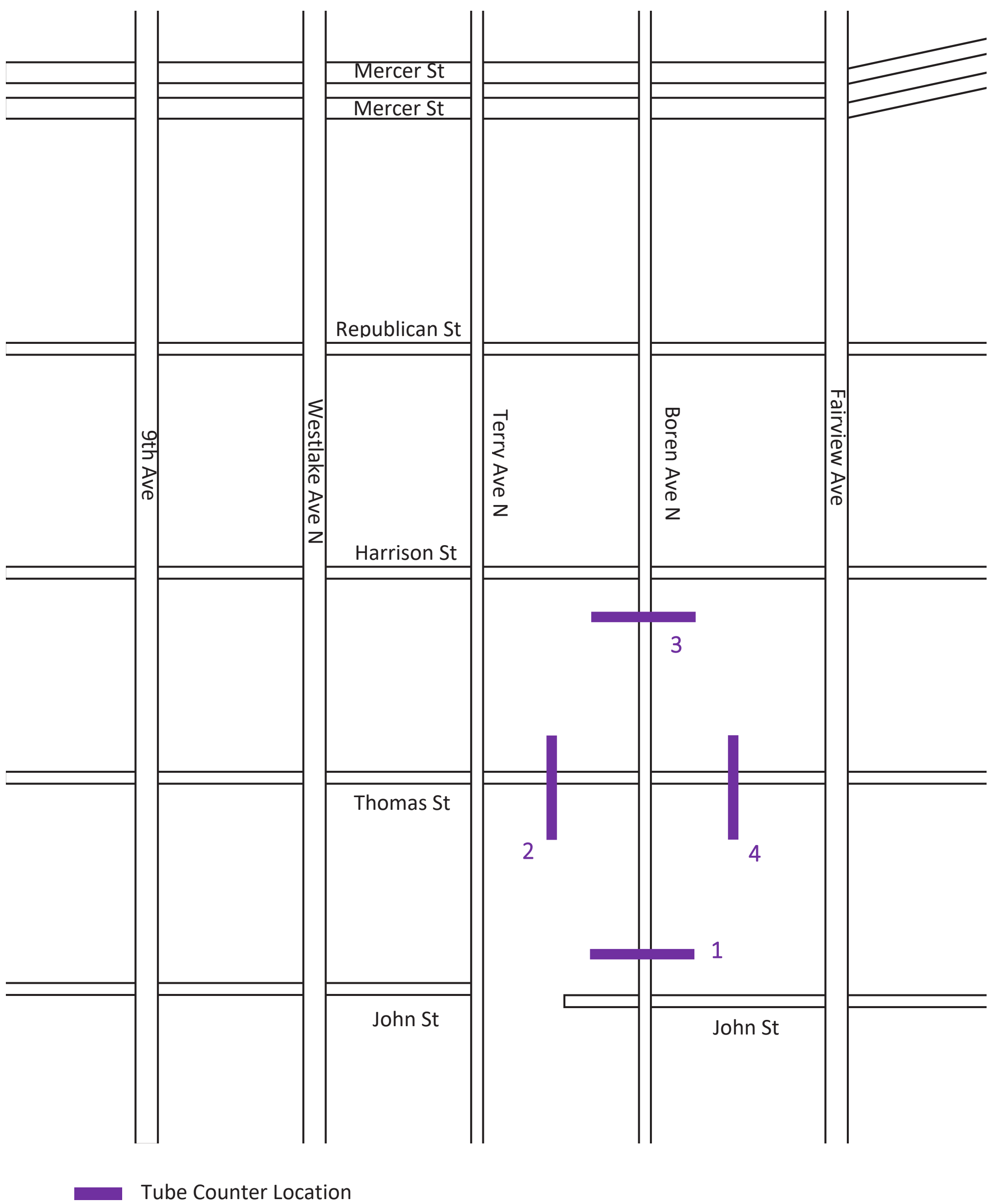
- Zone - Continuous curb spaces with a same purpose were grouped into one zone.
- Event type - One of parked, un-parked, passenger load, or passenger unload
- Event start and end time
- Location of event - One of curb, travel lane, or half-and-half
- Vehicle type - One of passenger vehicle, truck, large passenger van, or motorcycle
- TNC sign (Yes or No)
- Number of passengers boarding/alighting
- Passenger access door - One of front, back, or both
- Driver’s exit and return time
- Conflict – A situation where a user of the road (vehicle, bike, or pedestrian) is interrupted, forced to alter path, or gets engaged in a near-dangerous situation. Conflict categories were defined as vehicle-vehicle, vehicle-bike, vehicle-pedestrian, and pass through the oncoming traffic lane.
- Queue length

This data was collected on the three study block-faces for 8-10am and 2-6pm every day over the three phases of data collection.

3.2 Traffic Speed and Flow Data

This data was collected by IDAX Data Solutions through installing tube counters in the study area and converting tube data into quantitative measures of speed and volume. This data was collected for 24 hours every day over the three phases of data collection, and traffic speeds and volumes were given in 5-minute intervals for each of the north and south bound directions. The tubes were installed in four locations as shown in Figure 5.

Figure 5: Approximate locations of tube counters positioned in the study area



3.3 Additional Street Observations

Additional data was collected by UW research assistants to enrich interpretation of curb activity, traffic speed and flow data and to add depth and insight into the behaviors that might be missed by video or sensor data. The collected observations included number of pedestrians crossing the street not at the crosswalk and parking occupancy (i.e. number of vehicles parked at the curb).

The observations were conducted for one morning period (7:45-10:15 am) and two afternoon periods (4:15-6:45 pm) over the three phases of data collection. Pedestrian activity data was collected on Boren Ave N between Harrison and John Streets, and parking occupancy data was collected on four locations at Terry between John and Harrison, Harrison between Terry and Fairview, Fairview between Harrison and John, and Thomas between Fairview and Terry.

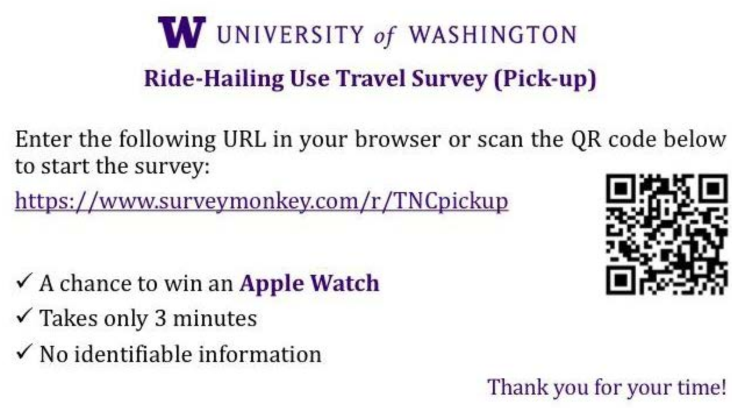
3.4 Passenger Survey

To collect additional data on travel behaviors and experiences of passengers, an intercept survey was designed and conducted in the study area. The survey questionnaire was approved by the UW institutional review board, and included questions on:

- satisfaction rate with pick-up/drop-off
- trip origin/destination (as cross streets) and trip purpose
- type of ride-hailing service (solo, pooled, premium/luxury, extra space)
- the number of passengers being paired with (if using pooled services)
- Any other mode used in conjunction with ride-hailing
- Mode substitution (if ride-hailing was not available)
- Frequency of using ride-hailing services
- Socio-demographic information, including age, gender, job status, income level, vehicle ownership

A copy of the survey questionnaire can be found in Appendix C. The survey was implemented in SurveyMonkey, and was hosted online in a format that can be easily accessed and filled out on a cell phone. UW research assistants present in the study area handed a card with the survey URL and a QR code to passengers waiting to be picked up or those being dropped off to fill out later (Figure 6). To encourage survey participation, a raffle prize of an Apple Watch was offered.

Figure 6: A sample passenger intercept survey card



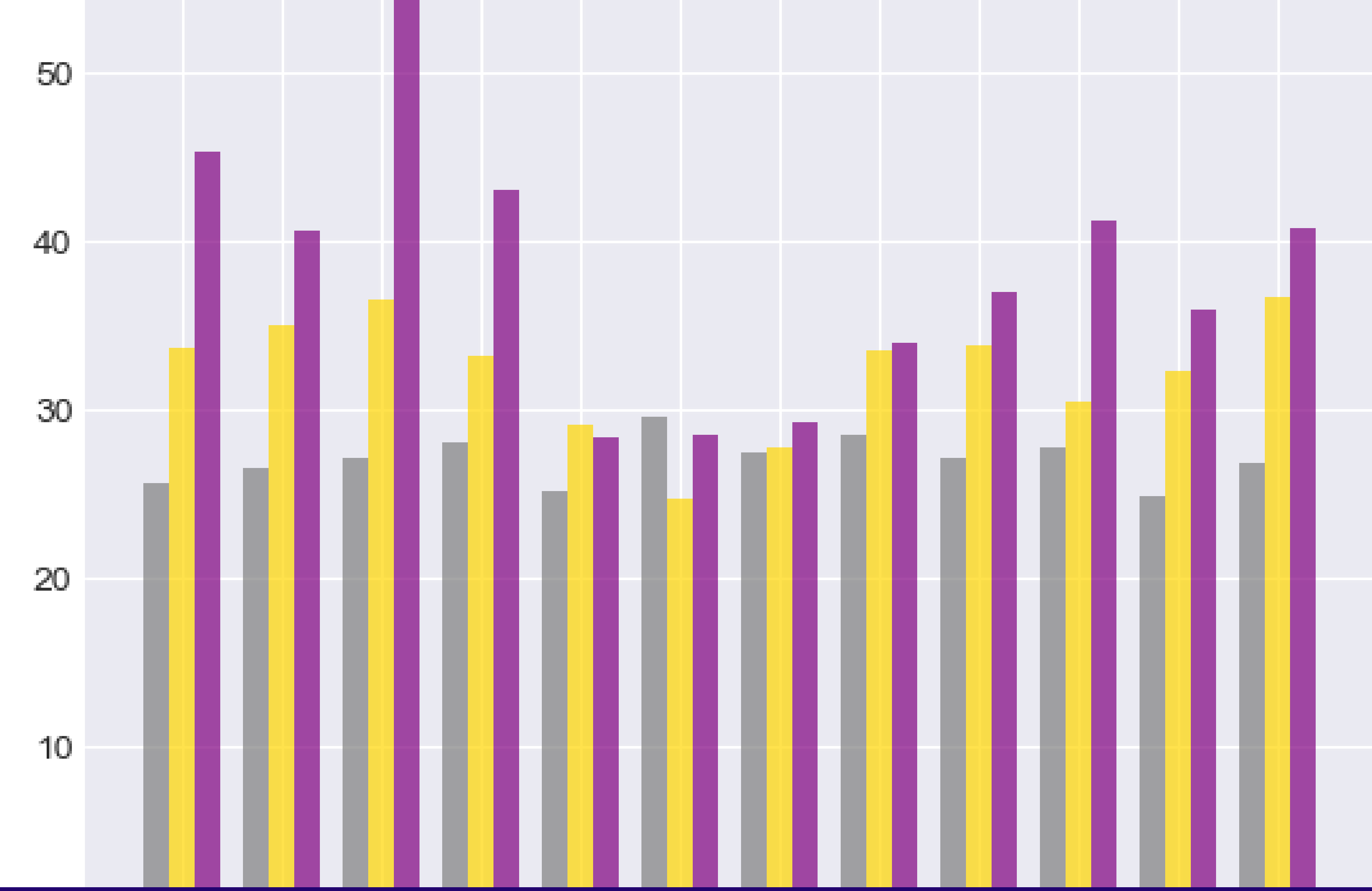
The survey was administered at several locations in the neighborhood, which correspond to the designated pick-up/drop-off points. The survey was conducted during morning (8:30-10:30 am) and evening (5-7 pm) periods each week. Surveying on the locations other than the three study block-faces was done over the same dates as phases 1 and 3 of data collection; however, since intercepting passengers would affect the vehicle stop time and traffic flow, we conducted the survey on the three study block-faces on a Monday and Tuesday of the week after the data collection phase dates. So, data collection dates for intercept surveys were 12/3-12/7 and 12/10-12/11 for Baseline phase and 1/7-1/11 and 1/14-1/15 for Phase 3 (Added PLZs + Geofence).

3.5 Supplementary Data Elements

The other data elements that are collected for the project are listed in Table 2.

Table 2: Supplementary Data Elements Collected for the Project

DATA ELEMENT	DATA DESCRIPTION	DATA COLLECTION DATES	PROVIDER
Turning Movement Counts	Counts of all movements at the intersections	7-11 AM and 1-7 PM, every day over the three phases of data collection	SDOT
Amazon Garage Data	Number of parking spaces, Number of vehicles in the garage at the start of each data collection period, and Number of vehicles entering/exiting the garage during the data collection period	7-11 AM and 1-7 PM, every day over the three phases of data collection	Amazon
Acyclica Sensors Data	Travel time estimates on nearby arterials	7-11 AM and 1-7 PM, every day over the three phases of data collection	IDAX Data Solutions (through SDOT's API)



4

Data Analysis

4 DATA ANALYSIS

4.1 Impacts on Traffic Speed

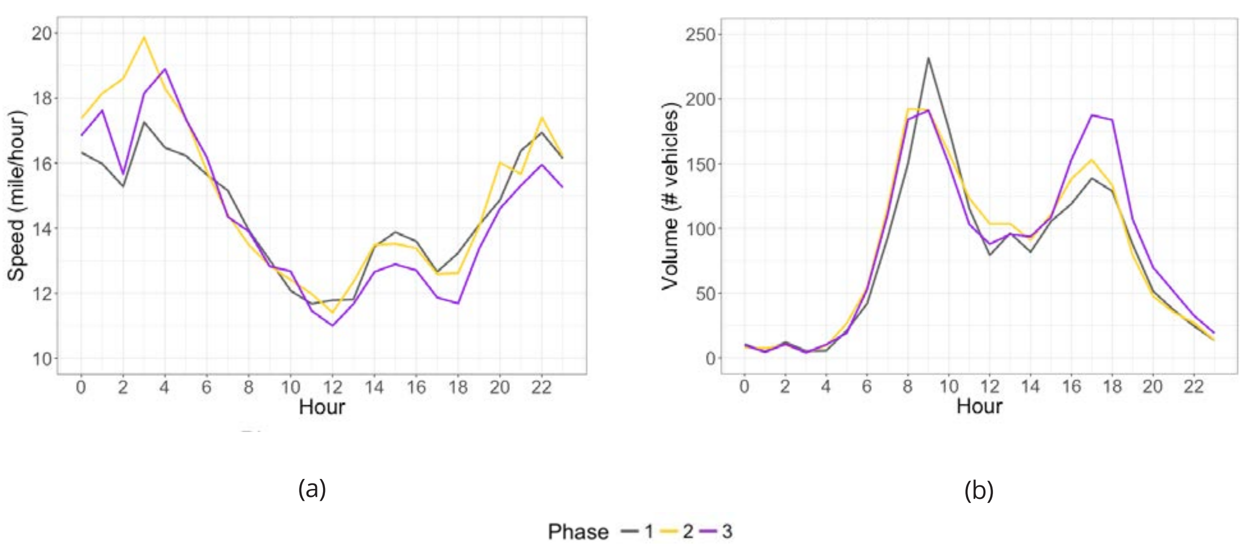
To explore the extent to which the changes of adding PLZs and geofencing affected traffic speed, a regression analysis was performed. The regression model studies the effects of traffic volume and other variables including the number of passenger drop-off and pick-up events on traffic speed.

The main variables used in the regression analysis and the main results from the analysis are reported in the following subsections. More technical details on the formulations and estimations of the regression model are reported in Appendix D.

4.1.1 Variable description

The variable of interest in this regression model is traffic speed, which is obtained by averaging the speed of individual vehicles that passed through the area in a given unit interval of time. Figure 7 shows the average vehicle speed and traffic volume in 1-hour time intervals (note that the 1-hr interval has been used for ease of plotting, but in the regression analysis 30-minute intervals were used). Figure 7(a) shows that the average traffic speed is at the lowest at noon, and then slow again at 6pm. Also, a decrease in average afternoon speed is observed after adding PLZs and implementing the geofence. However, as can be seen in Figure 7(b), traffic volume also increased over this period. The highest average volumes were recorded at 8-9am, with another peak at 5pm.

Figure 7: (a) Average vehicle speed (miles/hour) by hour of day (b) Average traffic volume (number of vehicles) by hour of day



4.1.2 Results

The detailed parameter estimates of the regression analysis performed using the data described above is reported in Appendix D, and a summary of the results is as follows:

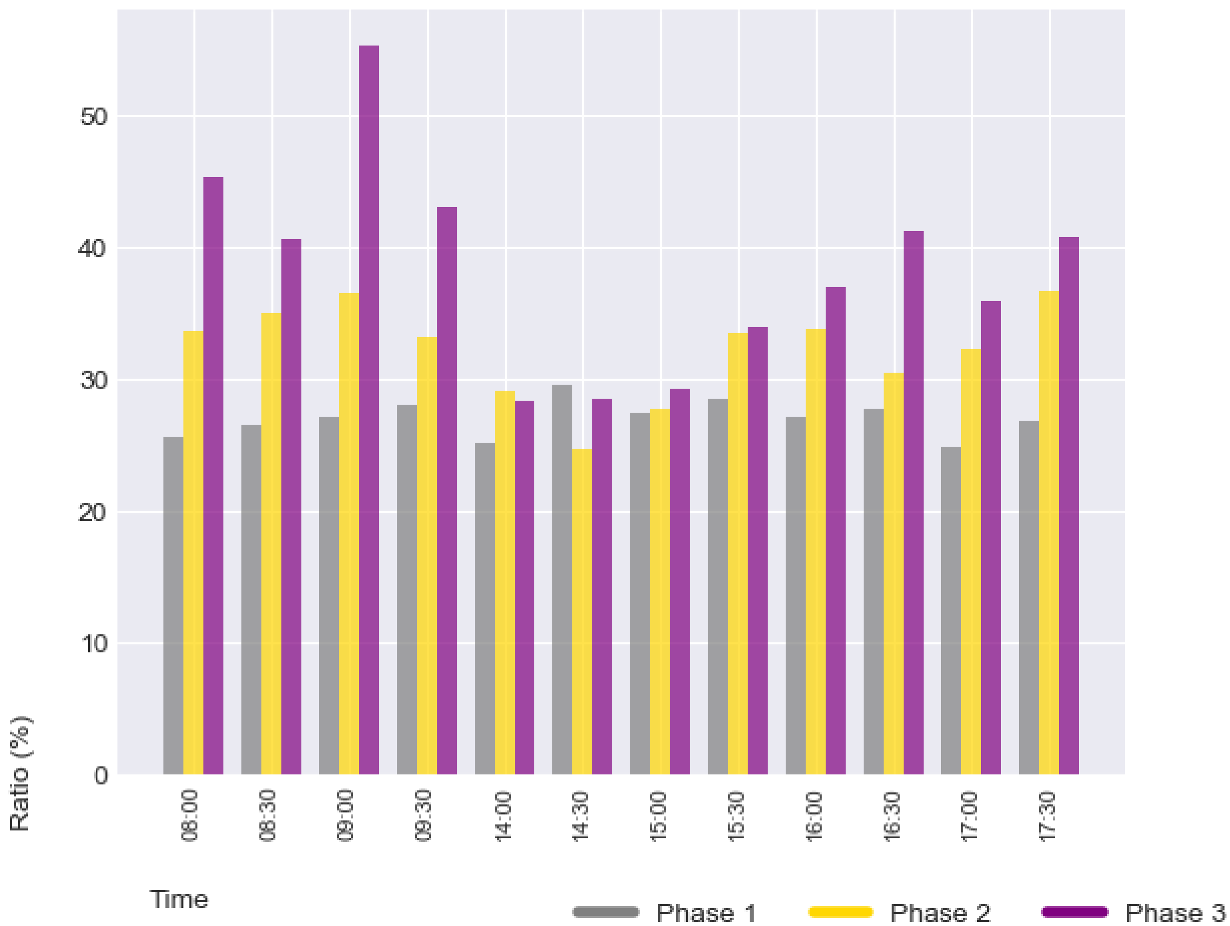
- Added PLZs (Phase 2) alone did not have a statistically significant effect on average traffic speed in either of the model formulations.
- Added PLZs and geofencing (Phase 3) had a statistically significant positive effect on traffic speed in three of the model formulations. In the selected model formulation, we observed that in Phase 1, adding 10 passenger drop-off events per half an hour decreased average traffic speed by 11.3%; while adding the same number of passenger drop-off events decreased average traffic speed only by 6.8% in Phase 3.
- When modelling the Northbound and Southbound traffic separately, it was found that there is a statistically significant positive effect of adding PLZs and geofencing for the Northbound traffic, but the effect is not statistically significant for the Southbound traffic.

4.2 TNC Demand and Operation

4.2.1 Passenger Pick-ups/Drop-offs versus Total Traffic Volume

Figure 8 shows average percentage of passenger pick-ups/drop-offs versus traffic volume in 30-minute intervals for each phase of data collection. According to this figure, passenger pick-ups/drop-offs (PUDO) constitute 25%-55% of traffic volume on the studied block-faces, and increased between from an average of 29% (8.7 PUDO out of 30.2 vehicles) in Phase 1 to 32% (11.0 PUDO out of 34.3 vehicles) and 39% (13.9 PUDO out of 35.4 vehicles) in Phases 2 and 3, respectively. The standard deviation of the percentage of passenger pick-ups/drop-offs throughout the day also increased from 1.3% in Phase 1 to 3.5% and 7.6% in Phases 2 and 3, respectively. The implementation of geofencing may have drawn PUDO activity to the study area and off of nearby arterial streets during Phase 3.

Figure 8: Passenger pick-ups/drop-offs as percentage of traffic volume (in 30-minute intervals) for all three block-faces and both directions



4.2.2 Vehicle Dwell Time

One of the research questions in this study is the extent to which vehicle dwell time changed after more PLZs were added and geofencing was implemented. The following subsections report the dwell time analysis results with respect to TNC vehicle operation, event location and number of passengers across different phases of study.

4.2.2.1 DWELL TIME ANALYSIS IN TERMS OF PICK-UPS AND DROP-OFFS

Figure 9 shows the cumulative distribution functions (CDF) of vehicle dwell times for pick-up and drop-off events separately. As can be seen, the drop-offs happened faster (which is not surprising), such that half of the drop-offs lasted 11 seconds or less, and 90% were under 1 minute and 12 seconds. For pick-ups, on the other hand, half of them were under 35 seconds and 90% of them were under 4 minutes and 41 seconds. Based on a Kolmogorov-Smirnov test, the difference between the two distributions was statistically significant at 0.1% significance level.

4.2.2.2 DWELL TIME ANALYSIS FOR EVENT LOCATIONS

Investigating the dwell times based on the location of events (Figure 10) showed that passenger pick-ups or drop-offs were the fastest when they took place in the travel lane, and then half way between street and the curb, versus at the curb. The median dwell times for events happening in the travel lane, half-and-half, and at curb were respectively 14, 20 and 33 seconds.

Figure 9: Empirical dwell time distributions of passenger pick-up and drop-off events across all three phases (all three block-faces and both directions)

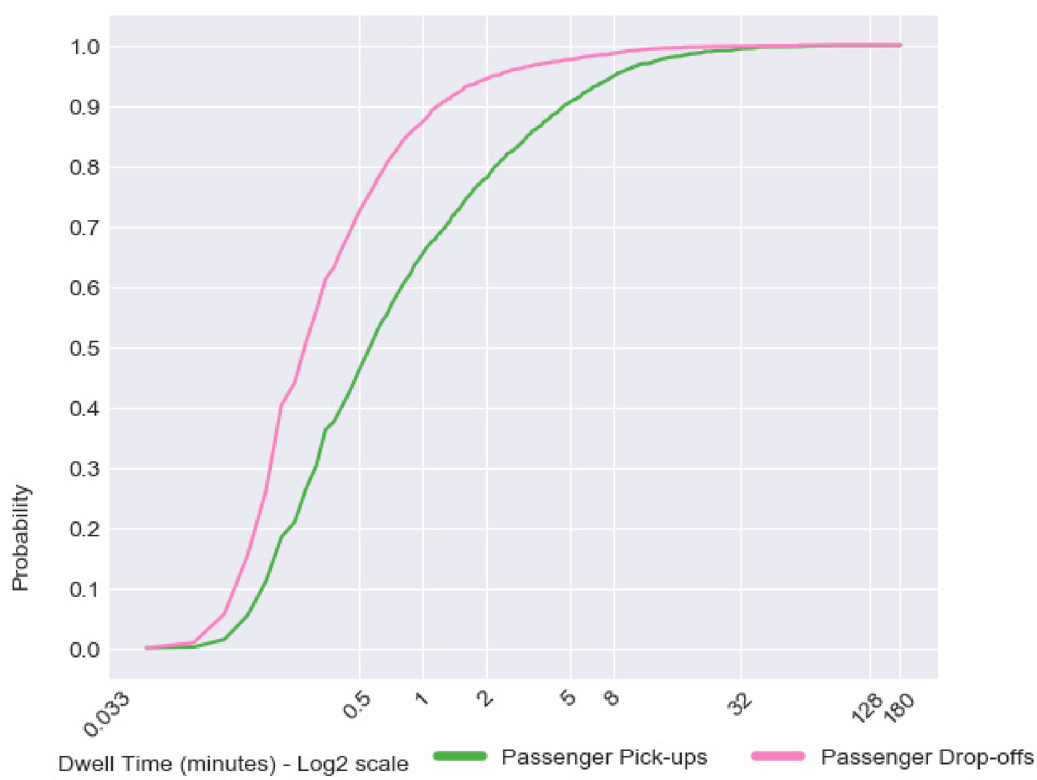
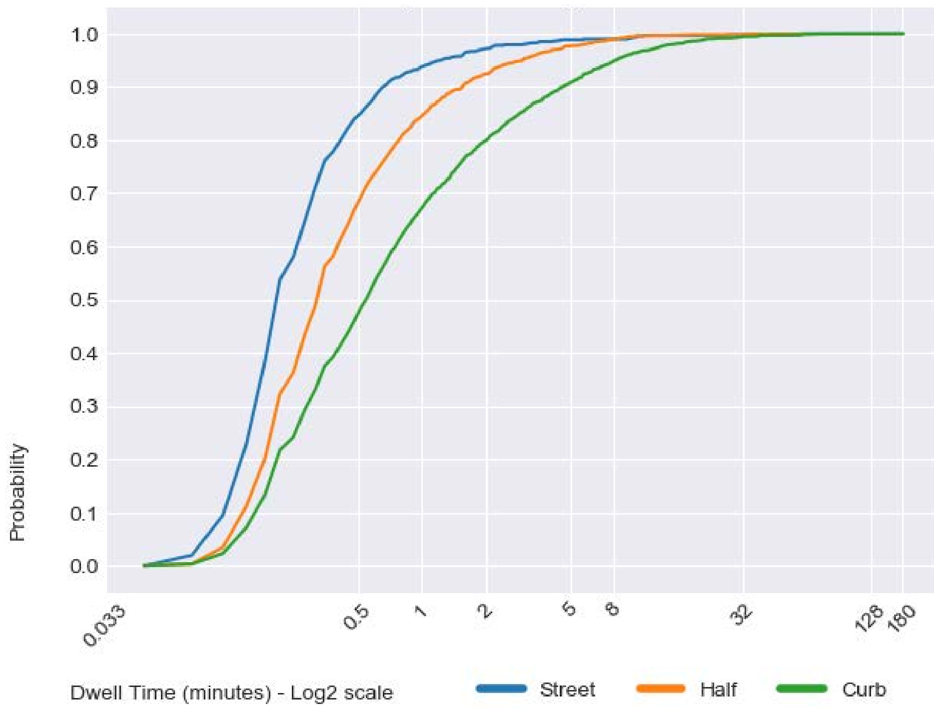


Figure 10: Empirical dwell time distributions of passenger pick-up and drop-off events for different event locations across all three phases (all three block-faces and both directions)



90% of the pick-ups/drop-offs occurring in the travel lane took less than 41 seconds, while the corresponding value for those happening somewhere between street and curb (half-and-half) and at the curb were 1 minute and 34 seconds, and 4 minute and 35 seconds, respectively. Based on a pairwise Kolmogorov-Smirnov test and a 3-sample Anderson-Darling test, the difference between dwell time distributions were statistically significant at less than 0.1% significance level.

4.2.2.3 DWELL TIME ANALYSIS FOR DIFFERENT PHASES OF STUDY

Figure 11 shows dwell time distributions of passenger pick-ups at curb for the three phases of study. As can be seen, passenger pick-ups on the curb were faster in Phase 3 (when added PLZs and geofencing were in place) than in Phase s 1 and 2. Based on a pairwise Kolmogorov-Smirnov test and 3-sample Anderson-Darling test, the difference between Phase 3 and the other two phases are statistically significant at a less than 1.5% significance level. Additional analyses on dwell times of passenger pick-ups per event location and study phase can be found in Appendix E.

Similar to pick-ups, drop-offs were faster in Phase 3 than in Phase s 1 and 2 (Figure 12). The difference between drop-off dwell time distributions in Phase 2 and 3 was statistically significant at a less than 2% level based on a pairwise Kolmogorov-Smirnov test and 3-sample Anderson-Darling test. In Phase 3, 90% of drop-off dwell time distribution were under 1 minute 12 seconds, and the dwell time value for the same proportion for Phase 2 was 1 minute 54 seconds.

Figure 11: Empirical dwell time distributions of passenger pick-ups at curb for the three phases of study (all three block-faces and both directions)

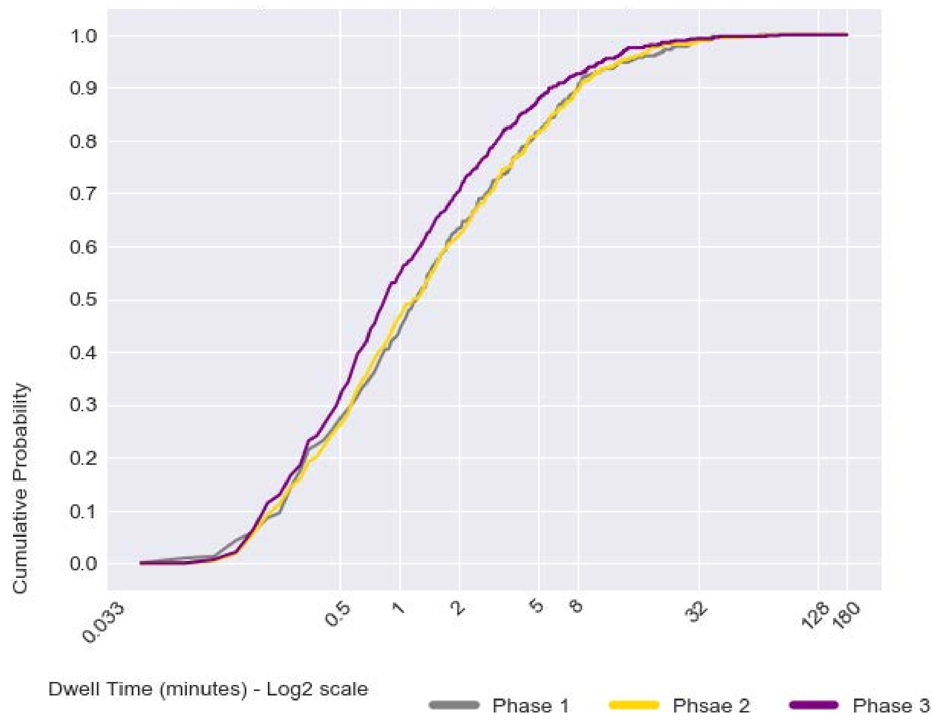
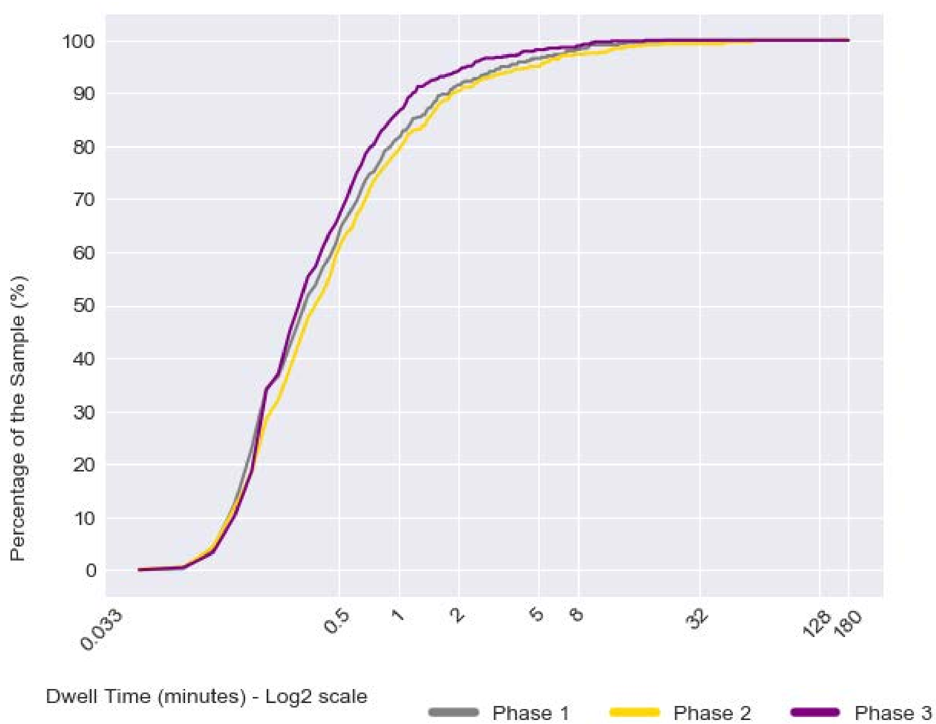


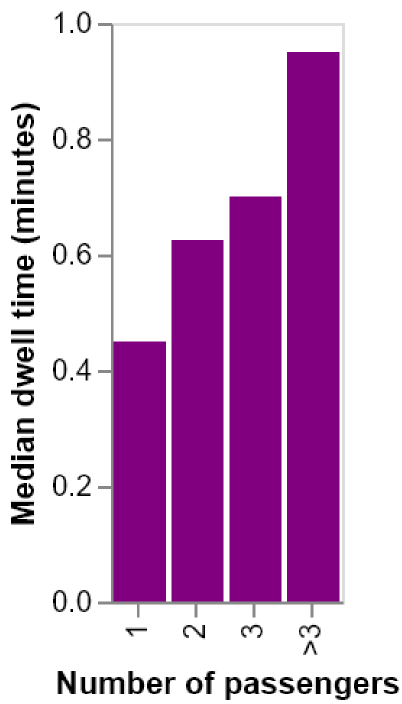
Figure 12: Empirical dwell time distributions of passenger drop-offs at curb for the three phases of study (all three block-faces and both directions)



4.2.2.4 DWELL TIME ANALYSIS FOR NUMBER OF PASSENGERS

Figure 13 shows median dwell time for the number of passengers picked up or dropped off by a vehicle, and intuitively it is observed as the number of passengers that a vehicle picks up or drops off increases, so does the time that the vehicle spends at the curb (or in the travel lane). It should be noted that the analysis reported here only considered the following vehicle types: passenger vehicle, large passenger vehicle, TNCs and Taxis. Motorcycles and trucks were excluded from this analysis due to the different nature of their operations.

Figure 13: Median dwell time and number of passengers picked-up/dropped-off



4.2.3 Passenger-Driver Contact Rate and Dispatch-to-Arrival Time

Another research question that this study investigated is whether adding new PLZs and geofencing made it easier for passengers and drivers to find each other. To answer this, we looked at two metrics provided by TNC companies: the passenger-driver contact rate and dispatch-to-arrival time. The passenger-driver contact rate equals the number of contacts (call or text) between passenger and driver before the pick-up divided by the number of TNC trips. The dispatch-to-arrival time represents the average travel time between the dispatch point to the pick-up point across all trips, and does not include the time that the driver waited for the passenger(s) to board the vehicle. Tables 4 and 5 show the statistics provided by Uber on these metrics. Lyft declined to provide these data to us.

The statistics show that in both Phases 2 (Added PLZs) and 3 (Added PLZs + Geofencing) the TNC vehicles arrived faster at the pick-up location, but it required more contacts between passengers and drivers to actually find each other. These changes are much bigger in Phase 3 when the geofence was applied compared to the Phase 2 where the signs were changed and more PLZs were added.

The faster arrival times may be explained by more PLZs being available in Phases 2 and 3, which could have made it easier for the drivers to find an appropriate location to stop. The dispatch-to-arrival times were even shorter in Phase 3, as the geofence directed the drivers to designated pick-up points. On the passenger side, however, it could have caused some confusion as passengers were used to getting picked-up at the point where they requested, while in Phases 2 and 3 (especially in Phase 3) they had to walk a few feet up or down the block to find their driver and board the vehicle. This would create the need for the passenger and/or the driver to make more contacts with each other.

Table 4: Passenger-driver contact rate changes (source: Uber)

CHANGE PERIOD	CHANGE PERCENTAGE
Baseline to Phase 2	1.92%
Phase 2 to Phase 3	4.70%
Baseline to Phase 3	6.71%

Table 5: Dispatch-to-arrival time changes (source: Uber)

CHANGE PERIOD	CHANGE PERCENTAGE
Baseline to Phase 2	-1.47%
Phase 2 to Phase 3	-7.65%
Baseline to Phase 3	-9.01%

4.3 Curb Use Changes

4.3.1 Compliance

One of the established research questions in this study was whether adding new PLZs and implementing geofencing increased compliant pick-up/drop-off behaviors in terms of using curb space versus stopping in the travel lane. Compliance in passenger pick-up/drop-off behaviors was studied by grouping pick-up/drop-off locations into in-lane authorized curb (curb or half-and-half in a PLZ), and un-authorized curb (curb or half-and-half at curbs with an allocation other than a PLZ, such as paid parking). Figures 14 and 15 show the compliance in pick-up and drop-off behaviors respectively.

As can be seen by comparing Figures 14 and 15, compliance in stop location choice for pick-ups looked similar to that for drop-offs. In both cases, the percent of un-authorized stops at the curb significantly drops in Phase s 2 and 3 compared to Phase 1. When considering the cause of this change, however, it should be noted that in Phases 2 and 3 the available PLZ spaces were about 13 times more than in Phase 1 (274 ft in Phases 2 and 3 versus 20 ft in Phase 1).

However, the percent of in-lane stops have also decreased in Phases 2 and 3 compared to Phase 1, and according to the chi-square test, these differences are significant for both pick-up and drop-off operations (See Appendix F).

Figure 14: Compliance in pick-up behaviors

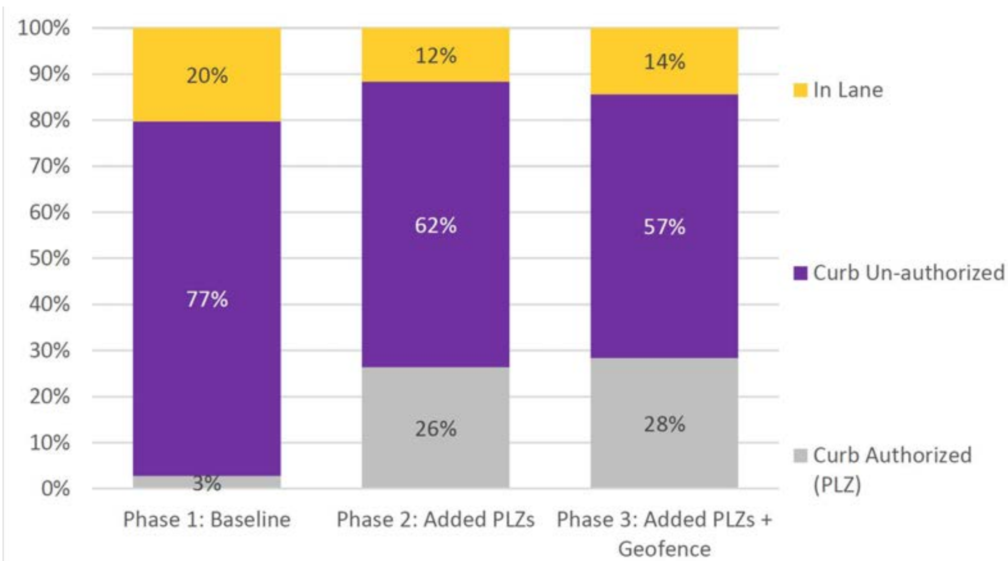
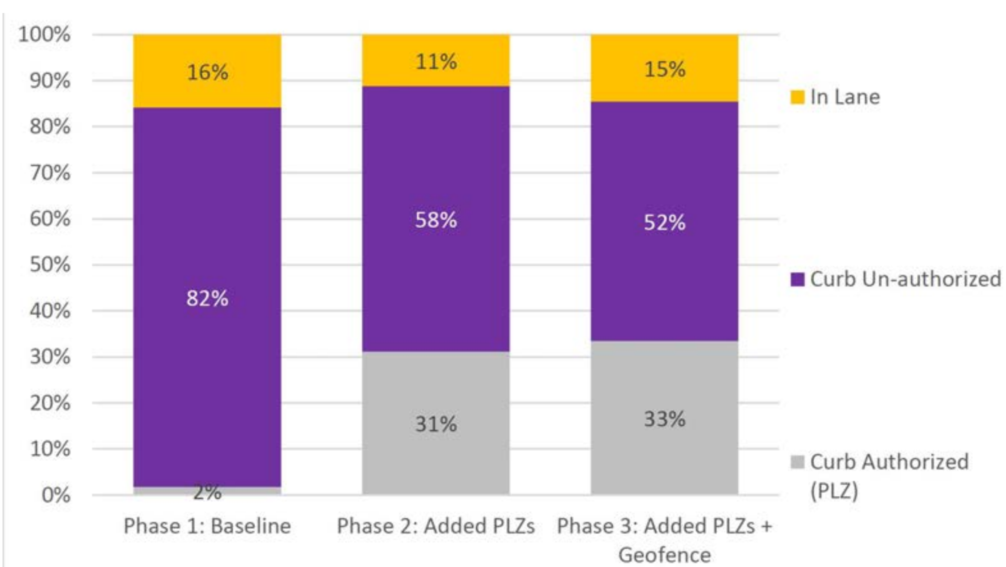


Figure 15: Compliance in drop-off behaviors

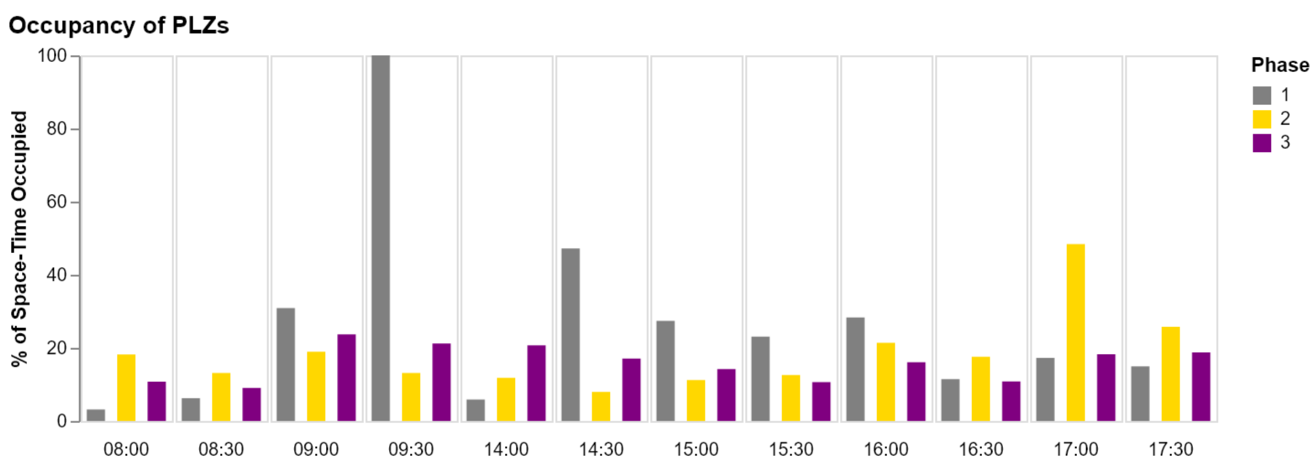


4.3.2 PLZ occupancy

To study the extent to which the added PLZs were utilized, we studied the occupancy of PLZs across the three phases of data collection. The total curb length dedicated to PLZ was 20 feet in the Baseline, versus 274 feet in Phases 2 and 3. To calculate the space used by vehicles and compare it to the PLZ length, a representative length for each vehicle type was considered (See Appendix G). The number of vehicles using the PLZ spaces were then aggregated into 30-minute intervals across all days of a week, and converted into a standard PLZ space.

Figure 16 shows the average occupancy of PLZs during the study time periods (8-10am and 2-6pm) in 30-minute intervals. In the Baseline (Phase 1) higher occupancy levels and larger variability (ranging from 3% to 100%) are observed, which is probably due to the very small PLZ space that could be easily filled with 1-2 vehicles. In Phases 2 and 3, however, the occupancy barely rose over 20%, except for an evening period (5-5:30pm) in Phase 2 where there was a spike in occupancy and approximately 50% of the space was occupied. Overall, Phase 2 (Added PLZs) showed lower occupancy levels than Phase 3 (Added PLZs + Geofencing) in the first half of the morning peak (8:00-9:00) and in the second half of the afternoon peak (16:00-18:00).

Figure 16: Average percentage of PLZs being occupied in 30-minute intervals



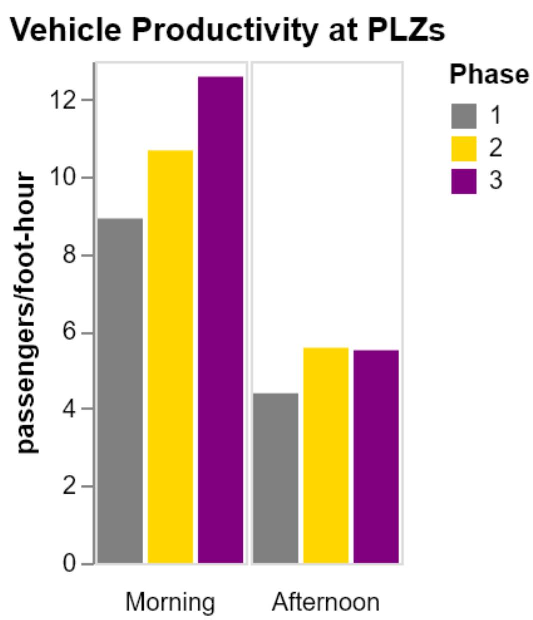
4.3.3 Vehicle Productivity at PLZs

Another measure for studying curb utilization is vehicle productivity at PLZs, which is defined as the number of individuals served by a vehicle per unit of curb space and per unit of time. For instance, a 15-foot long passenger vehicle that takes 30 seconds to unload one passenger would have a productivity of ((1/15/0.5)*60=) 8 passengers/foot-hour.

To calculate the vehicle productivity, we excluded motorcycles and trucks, and only considered large and regular passenger vehicles, TNC vehicles and taxis. To be consistent with passenger pick-up/drop-off operations in counting the individuals served by a vehicle, the number of individuals served by the vehicles that parked or un-parked (ended parking and left the curb space) at a curb were multiplied by two, because these vehicles first unload and then load the individuals.

Figure 17 shows the average productivity of vehicles stopping at PLZs to load/unload individuals by time of day across the study phases. As can be seen, in both morning and afternoon periods, the vehicle productivity increased from Phase 1 to Phase 3, with the difference that in the morning, the vehicle productivity also increased from Phase 2 to Phase 3, while in the afternoon no change was observed between phases 2 and 3.

Figure 17: Vehicle Productivity at PLZs by phase and time of day



4.3.4 Curb Space Productivity

The productivity of the curb space is calculated as follows:

$$Space\ productivity = \frac{Total\ passengers\ served\ at\ the\ curb}{Curb\ length\ \times\ Duration\ of\ study\ period}$$

Where *Curb length* refers to the length of the curb where the vehicle stops occurred; *Duration of study period* refers to either the morning (2 hours) or afternoon (4 hours) periods when data was being collected; and *Total passengers served at the curb* is calculated as the sum of:

- The number of passengers picked up
- The number of passengers dropped off
- The number of individuals served by the vehicles that either parked or un-parked during the study period.
- Two times the number of individuals served by the vehicles that both parked and un-parked during the study period – as these vehicles both unloaded and loaded individuals.

Curb space productivity was estimated for two curb segments in the study area:

- Old and new PLZs: This includes all the 274 feet of curb space along the study block-faces that was allocated to PLZ during Phases 2 and 3. During Phase 1, this curb length constitutes 20 feet of PLZ and 254 feet of two-hour paid parking.
- Fixed paid parking: This includes approximately 216 feet of curb space along the study block-faces that remained as two-hour paid parking across all three phases of the study.

Table 6 shows average productivity of the above curb segments during the morning and afternoon time periods on a weekday. As can be seen for both segments, space productivity increased from Phase 1 to Phases 2 and 3. For the PLZ segment, across all phases, space productivity was higher in the morning than in the afternoon, while this is not the case for the fixed paid parking segment.

Table 6: Average space productivity of PLZ and paid parking spaces

TIME PERIOD	PHASE	OLD AND NEW PLZS (PASS/FT/HR)	FIXED PAID PARKING (PASS/FT/HR)
Morning	1 (Baseline)	0.14	0.06
Afternoon		0.05	0.08
Morning	2 (Added PLZs)	0.14	0.12
Afternoon		0.09	0.10
Morning	3 (Added PLZs and Geofencing)	0.17	0.15
Afternoon		0.10	0.11

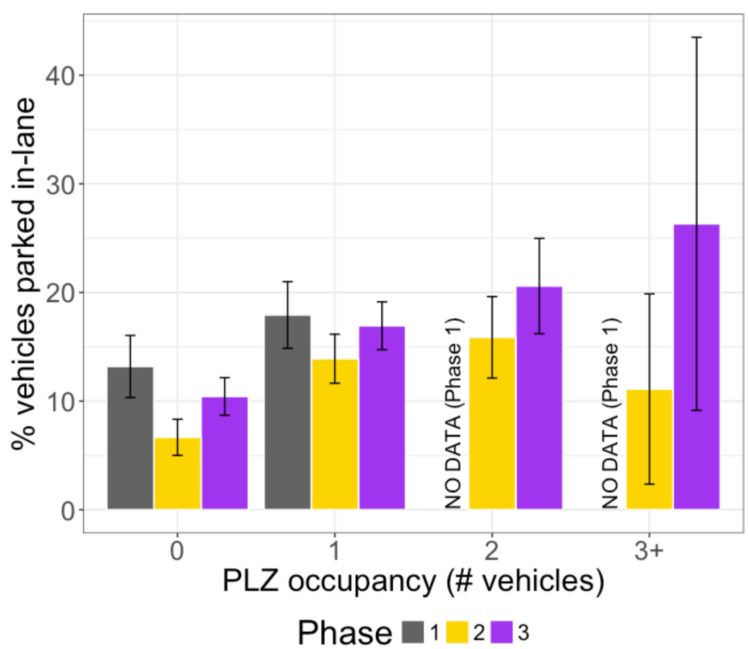
4.3.5 In-lane Parking Behavior

One of the established research questions is whether the driver's choice of stopping in the travel lane is a consequence of a lack of curb availability. To answer this, we studied the correlation between a driver's choice of stopping in the travel lane and the number of vehicles occupying the PLZs at the time when the driver arrives at the block-face. Figure 18 shows the percentage of vehicles picking up or dropping off passengers in the travel lane in terms of the number of vehicles occupying the PLZs on the block-face where the vehicle stopped upon arrival.

As can be seen, in Phase 1 (Baseline), arriving vehicles observed either a completely free PLZ or one vehicle parked; this is because in the Baseline only one parking space was allocated as PLZ. During the Baseline, when the PLZ was free, only 9% of vehicles chose to stop in the travel lane, while when it was full, 15% of vehicles stopped in-lane and the rest stopped at paid-parking spaces.

During Phases 2 and 3 more PLZs were added, and therefore there are cases where two and more vehicles were simultaneously occupying the PLZs on a block-face. The results showed that an increase in the PLZ occupancy increased the likelihood of stopping in the travel lane. In Phase 3, the percentage of vehicles that stopped in the travel lane when PLZs were empty was 10%, while that percentage increased to 17%, 20% and 26% respectively for occupancy rates of one, two, and three or more vehicles. Phase 2 showed a similar trend as Phase 3, except that in Phase 2 the increases in the percentage of in-lane stops for occupancy rates of one and two vehicles were larger than that of the three or more vehicles occupancy rate: the percentage of vehicles stopped in the travel lane increased from 7% when PLZs were empty to 14%, 16% and 11% when PLZs were occupied by one, two, and three or more vehicles, respectively. However, it should be noted that since very few vehicles experienced an occupancy rate of three or more vehicles upon arrival at PLZs, the confidence intervals of in-lane stopping percentages for that occupancy rate are much larger than those of the one- or two-vehicle occupancy rates.

Figure 18: Pick-up/Drop-off in-lane parking



Percentage of vehicles picking up or dropping off passengers in the travel lane in terms of the number of vehicles occupying the PLZs on the corresponding block-face. The vertical lines represent the 95% confidence interval. (In Phase 1, there was only a 20-ft PLZ available, and it would be impossible for more than one vehicle to occupy it.)

In general, in the study area, vehicles arriving to pick up or drop off passengers rarely experienced high occupancy rates of the PLZs; however, in almost all cases, an increase in the PLZ occupancy increased the likelihood of stopping in-lane. It is also worth noting that in all phases, 7-10% of the arriving vehicles still chose to stop in the travel lane even when no vehicle was occupying the PLZ spaces.

4.4 Safety Impacts

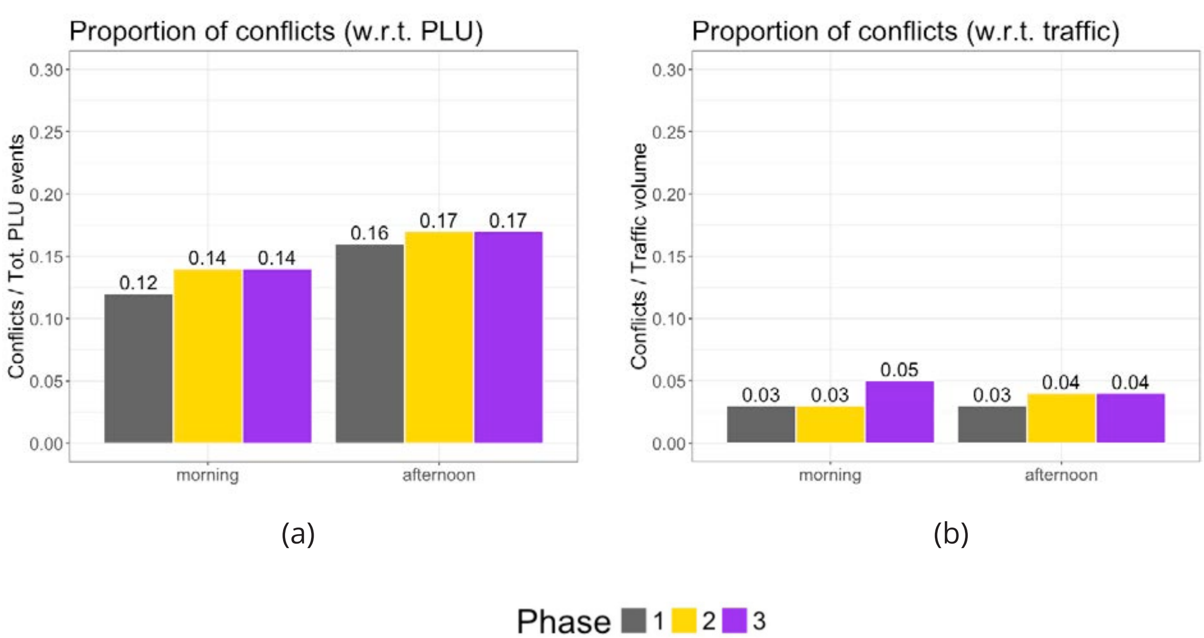
4.4.1 Conflicts

To investigate the impacts of changes on traffic safety in the study area, we studied the number of conflicts before and after the changes. Conflicts are defined as a situation where a user of the road (vehicle, bike, or pedestrian) is interrupted, forced to alter path, or gets engaged in a near-dangerous situation. We defined conflict categories as vehicle-vehicle, vehicle-bike, vehicle-pedestrian, and pass through the oncoming traffic lane.

Figure 19 shows the average number of conflicts divided by the total number of passenger pick-up and drop-off events (Figure 19(a)) and by the total traffic volume (Figure 19(b)) in the morning and afternoon periods. And as can be seen, the changes in conflict rates across the three phases of study were not statistically significant.

We also modeled the passenger pick-up/drop-off events as a series of Bernoulli trials, in which each event outcome can be a “conflict” or “no conflict”. A binomial regression of the probability of an event resulting in a conflict was then derived as a function of several explanatory variables, including total traffic volume, number of pick-up events, number of drop-offs and a set of indicator variables for adding PLZs and geofencing. The results showed no statistically significant effect of the adding PLZs and geofencing on the probability of a pick-up/drop-off event being a conflict. The regression parameters estimates are reported in Appendix H.

Figure 19: (a) Proportion of conflicts with respect to passenger pick-up/drop-off events; (b) Proportion of conflicts with respect to total traffic volume



4.5 Passenger Experience

One of the main research questions in the present study was how the TNC passengers responded to the changes of adding PLZs and implementing geofences. To answer this, we conducted a passenger survey as explained in section 3.4. The survey response rate was relatively high, with 19% for Phase 1 and 24% for Phase 3 (Table 7).

Table 7: Response Rate

<table>
<tr><th>PHASE</th><th>ACTIVITY</th><th>NUMBER OF CARDS GIVEN</th><th>NUMBER OF COMPLETED SURVEYS</th><th colspan="2">RESPONSE RATE</th></tr>
<tr><td rowspan="2">1</td><td>Pick-up</td><td>170</td><td>33</td><td>19%</td><td rowspan="2">19%</td></tr>
<tr><td>Drop-off</td><td>107</td><td>19</td><td>18%</td></tr>
<tr><td rowspan="2">3</td><td>Pick-up</td><td>118</td><td>28</td><td>24%</td><td rowspan="2">24%</td></tr>
<tr><td>Drop-off</td><td>146</td><td>36</td><td>25%</td></tr>
</table>

Figures 20 and 21 show travelers' satisfaction statistics respectively for pick-ups and drop-offs. As can be seen by comparing Figures 20 and 21, travelers satisfaction with pick-up and drop-off has increased following the curb reallocation and geofence implementation. Although 1 person ranked her pick-up experience as "Awful" in Phase 3, 79% of passengers rated their pick-up experience between "Excellent" and "Good" in Phase 3; whereas the corresponding number for Phase 1 is 72%. This difference is even larger for drop-offs, with all passengers rating their drop-off experience in Phase 3 at least "Good", and 97% rating it either "Excellent" or "Very Good"; whereas in Phase 1, 89% of customers rated their experience at least "Good". It is worth to mention that the rating scale was the same for pick-ups and drop-offs.

An ordinal logistic regression model was also applied to the survey data to test the significance of changes in Phase 3 versus the Baseline. The model results are presented in Appendix I, and confirm that the added PLZs and geofencing significantly contributed to passenger satisfaction level.

Table 8 presents a summary of the socio-demographic and trip characteristics of ride-hailing users in the area. As can be seen the sample skews toward male, young (25-34), higher-income individuals (65% or more of the respondents reported an individual annual income of $100K). About 40-50% of our sample reported making a work-related trip, and more than half of the sample were frequent ride-hailing users (defined as using ride-hailing services at least once a week). In both phases, more than half of the respondents reported having used a private economy ride (e.g. UberX, Lyft) and 70% or more took ride-hailing services all the way from origin to destination on their trip. Among those who used ride-hailing in connection with another transportation mode for their trip, a majority reported linking with public transit (bus, light rail, trolley). Nearly half the respondents stated that they would have taken public transit if ride-hailing were not available, and about one-third said they would have walked.

Figure 20: Passenger Satisfaction for Pick-up Behaviors (N=60)

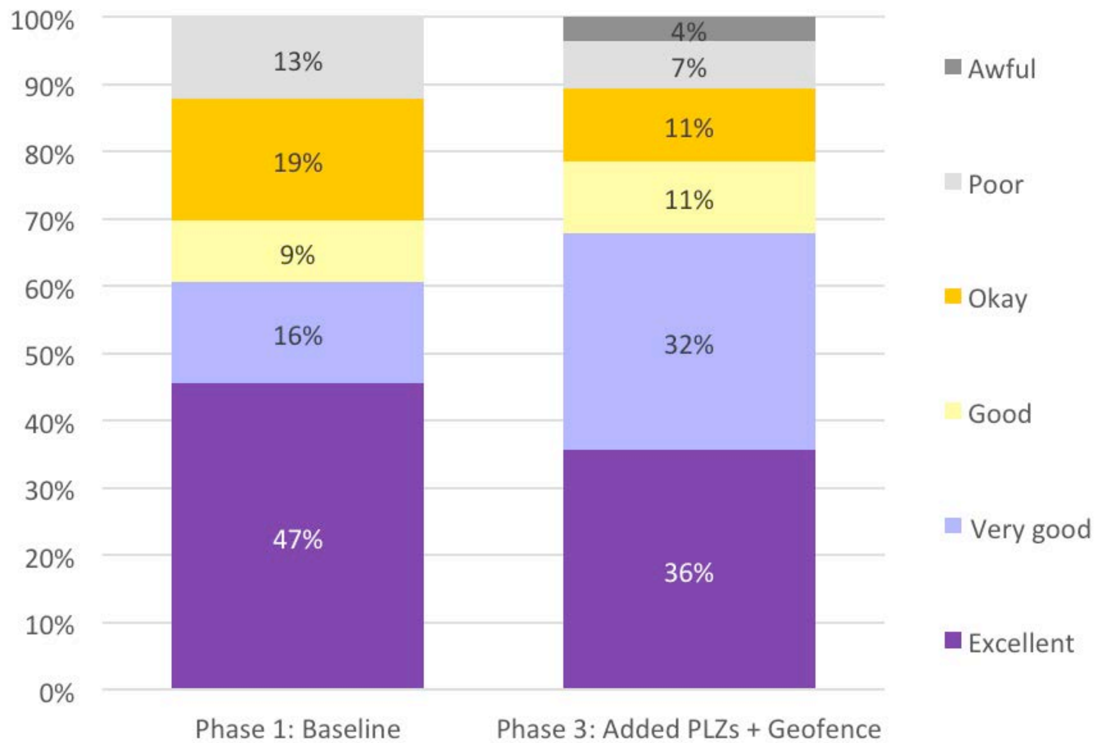


Figure 21: Passenger Satisfaction for Drop-off Behaviors (N=55). There were no poor or awful ratings.

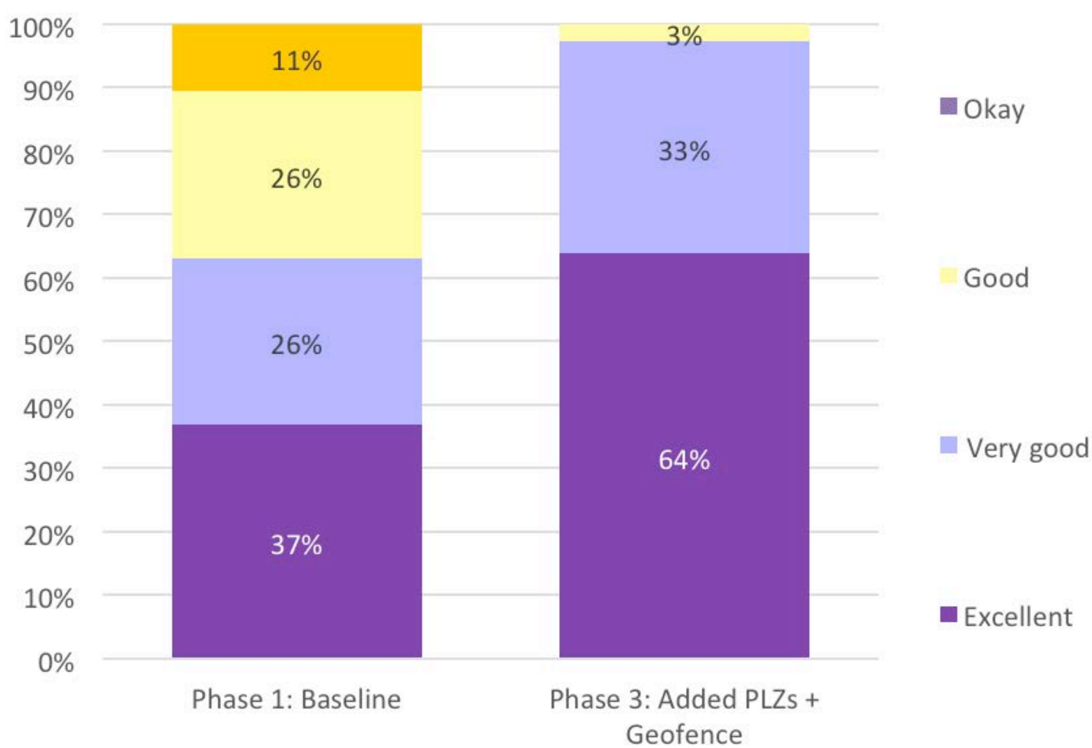
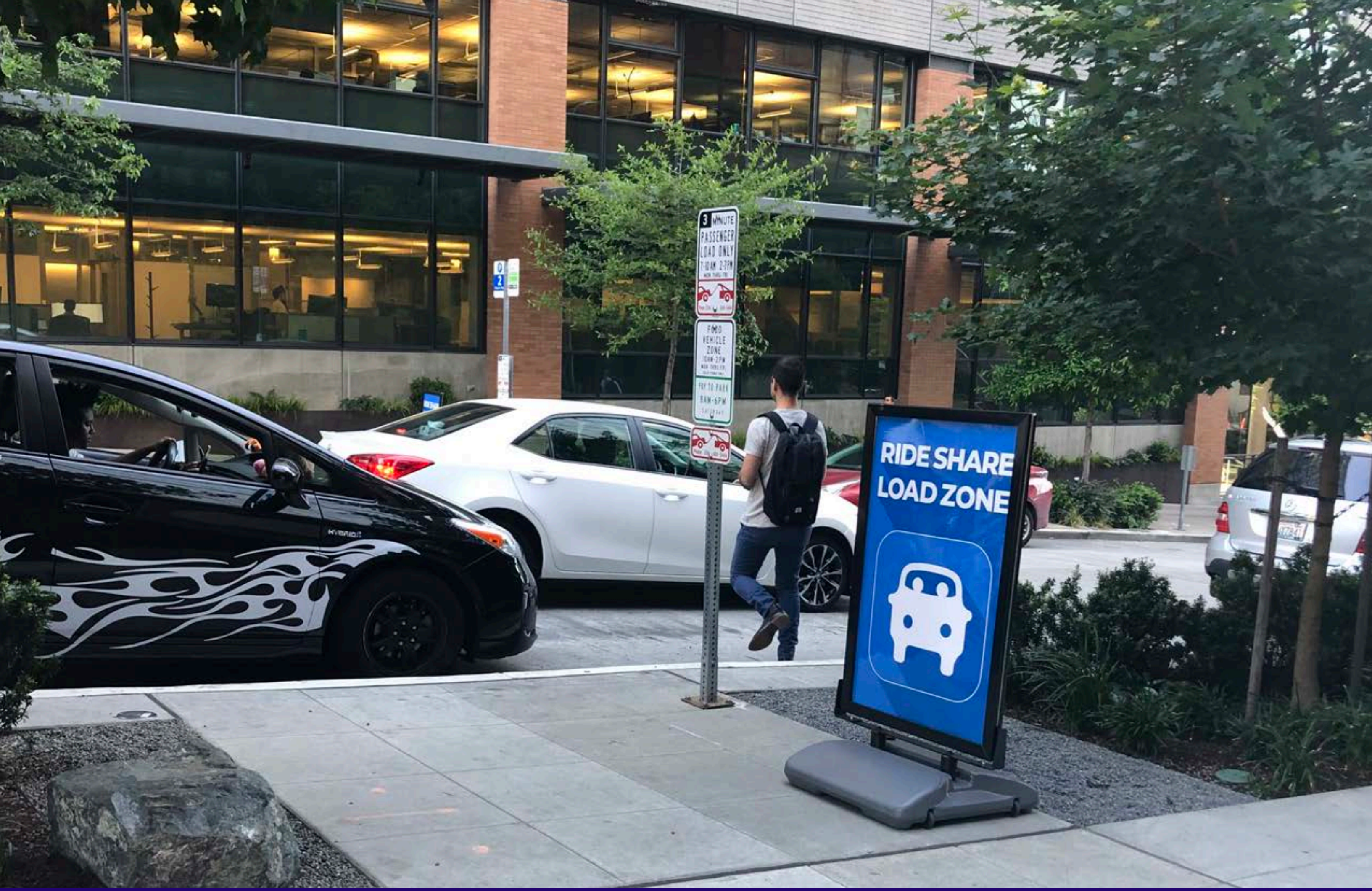


Table 8: Summary of socio-demographic and trip characteristics of ride-hailing users in the area

QUESTION	CATEGORIES	PHASE 1	PHASE 3
What is your gender?	Female	23%	45%
	Male	73%	55%
	Prefer not to answer	4%	0%
What is your age?	18-24	13%	8%
	25-34	56%	72%
	35-44	25%	19%
	45-64	6%	2%
What is your personal annual income level?	Under $15,000	4%	6%
	$15,000 to $29,999	0%	0%
	$30,000 to $49,999	6%	3%
	$50,000 to $74,999	10%	6%
	$75,000 to $99,999	15%	11%
	$100,000 to $150,000	29%	50%
	$150,000 to $200,000	19%	14%
	Over $200,000	17%	9%
Which of the following best describes your current job situation?	Employed work from home	10%	2%
	Employed outside home	85%	97%
	Student	4%	2%
	Retired	2%	0%
What was the purpose of your trip?	Home	25%	25%
	Work	38%	53%
	Personal Business (Bank, Doctor Appointment)	10%	3%
	Recreation/Meal/Social	19%	16%
	Shopping	2%	0%
	other (P&R, Hotel, Gym)	6%	3%
What service did you request?	Private economy ride (UberX, Lyft)	58%	51%
	Shared door-to-door ride (Uber Pool, Lyft Shared)	27%	42%
	Shared with a short walk (Express Pool)	13%	5%
	Premium/luxury vehicles (Uber Black, Uber Select, Lyft Lux, Lyft Lux Black)	0%	2%
	Extra Space (Uber XL, Black SUV, Lyft XL, Lyft Lux Black XL)	2%	0%

Table 8: *continued*

QUESTION	CATEGORIES	PHASE 1	PHASE 3
If you didn't use ride-hailing (e.g. Uber or Lyft) all the way from your origin to destination on this trip, what was the other mode of transportation that you used? *(This was a two-part question.)*	Just Ride-hailing	77%	69%
	Bike	2%	2%
	Drive personal car	6%	5%
	Car-share	2%	3%
	Picked up/Dropped off (by a friend or family member)	2%	3%
	Public Transit (Bus, Link, Streetcar)	12%	19%
How would you have made this trip if ride-hailing (e.g. Uber or Lyft) were not available?	Walk	29%	36%
	Bike	4%	2%
	Drive personal car	10%	8%
	Car share	8%	6%
	Picked up/Dropped off (by a friend or family member)	2%	3%
	Public Transit (Bus, Link, Streetcar)	48%	45%
How often do you generally use ride-hailing services (e.g. Uber or Lyft)?	Daily	13%	23%
	A few times a week	27%	42%
	Weekly	13%	8%
	A few times a month	33%	22%
	Monthly	4%	2%
	Less than once a month	10%	3%



5

Discussion of Site-Specific Characteristics

5 DISCUSSION OF SITE-SPECIFIC CHARACTERISTICS

This section highlights additional site-specific characteristics that we feel are important to note as they will be relevant to traffic in the neighborhood.

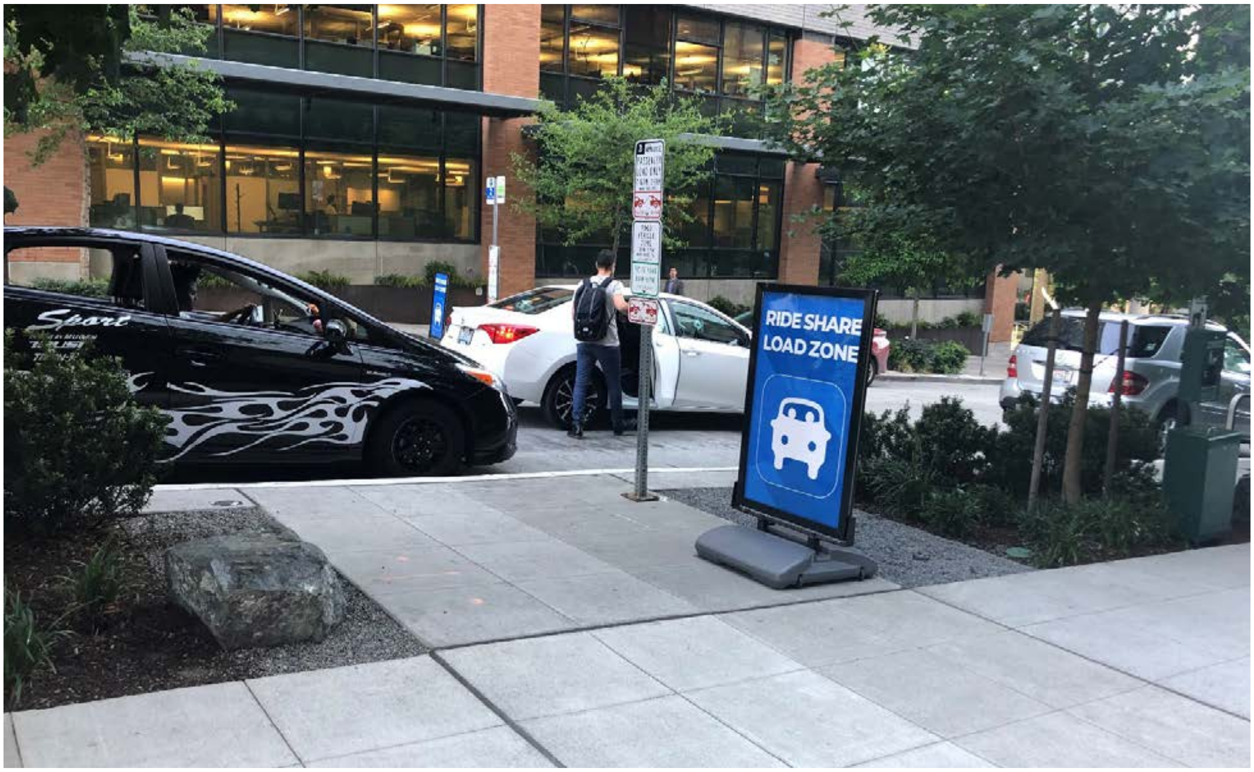
5.1 Street Design

Below is a list of street design related items that are noteworthy about the study area.

- *Slow speed limits* - The speed limit on the study blocks was 25 mph and there were stop signs at all intersections.
- *Numerous construction sites* - There were numerous construction activities going on in the close proximity of the study area. A list of construction activities is provided in Appendix J.
- *Lack of lighting* - The data collection was done in months of December and January, when days are very short in Seattle and it gets dark after 4pm. The study blocks were also not very well lit.
- *Less formal infrastructure* - Some of the curbs were semi-permanent (hand-formed asphalt as opposed to formed concrete) and also lacked appropriate street paint. On Boren Ave N between Thomas and Harrison streets, there was no crosswalk between the Amazon buildings on two sides of the street, however, there were curb bulbs reducing the crossing distance (Figure 22) and pedestrians were crossing the street frequently. In addition to the signs installed by SDOT, Amazon placed sandwich board signs for designated pick-up/drop-off locations on sidewalks (Figure 23), and although these signs helped increase the visibility of designated locations, their sandwich board structure implied a temporary situation. These create a sense of less formality for the neighborhood infrastructure in the study area.

Figure 22: Curb bulbs and reduced crossing distance in the area between the Amazon buildings on two sides of Boren Ave N between Thomas and Harrison streets

Figure 23: Sandwich board signs for designated pick-up/drop-off locations in the study area



5.2 Amazon Parking Garages

There are three Amazon off-street parking garages in the study area: Arizona, Dawson/Ruby and Houdini. The location of entrance/exit point for each garage is shown in Figure 24. During peak hours, these garages attract/dump a significant number of vehicles to Thomas and Harrison streets, which cause long queues and traffic congestion on these streets as well as Boren Ave N.

Figure 25 shows how big the number of vehicles entering/exiting these garages are by dividing the hourly vehicle flow from/to each parking garage to the hourly traffic volume on the block where the garage's entrance/exit is located. As can be seen, vehicles entering/exiting the garages are equal to 35-60% of street vehicles in the morning and 20-40% of street vehicles in the afternoon.

The traffic volume on the street was estimated using turning movement counts from the intersections of Boren Ave N & Thomas St and Boren Ave N & Harrison St, and only sedans and light goods trucks were considered. Both the street traffic volume and the garage ingress/egress flow were observed for 7-11 AM in the morning and 1-7 PM in the afternoon, and the percentages reported in Figure 25 are being averaged across all days of data collection (a total of 15 weekdays).

Figure 24: Approximate locations of Amazon parking garages entry/exit points in the study area

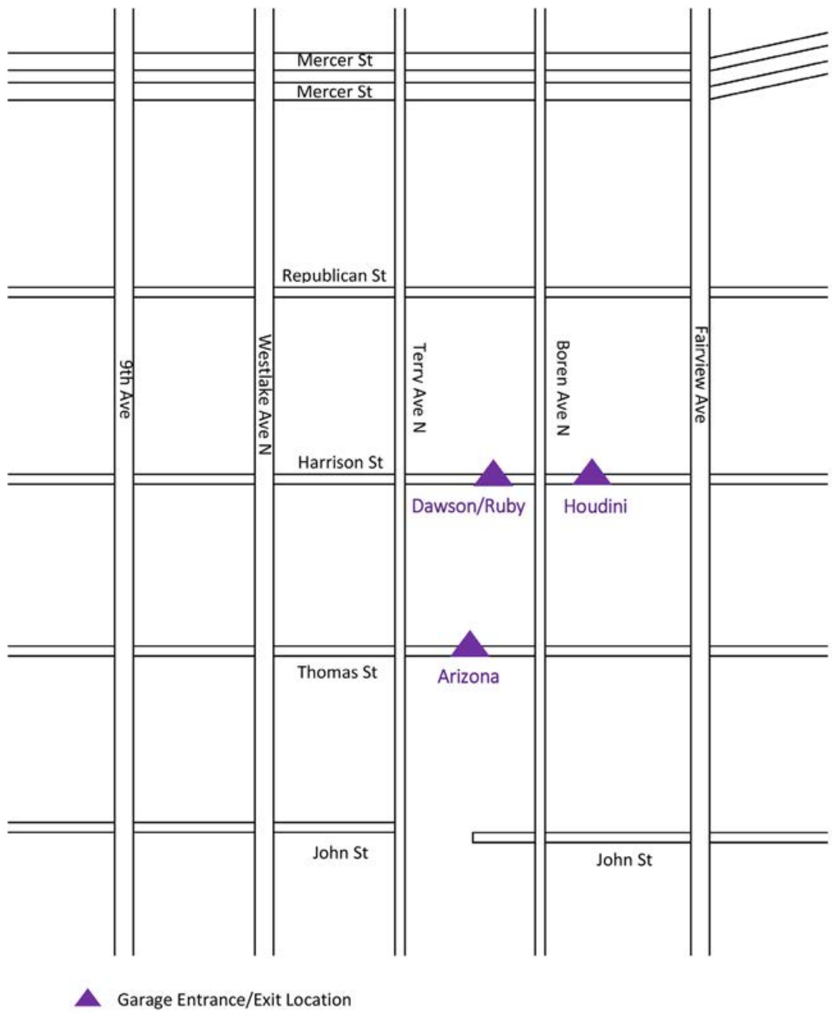
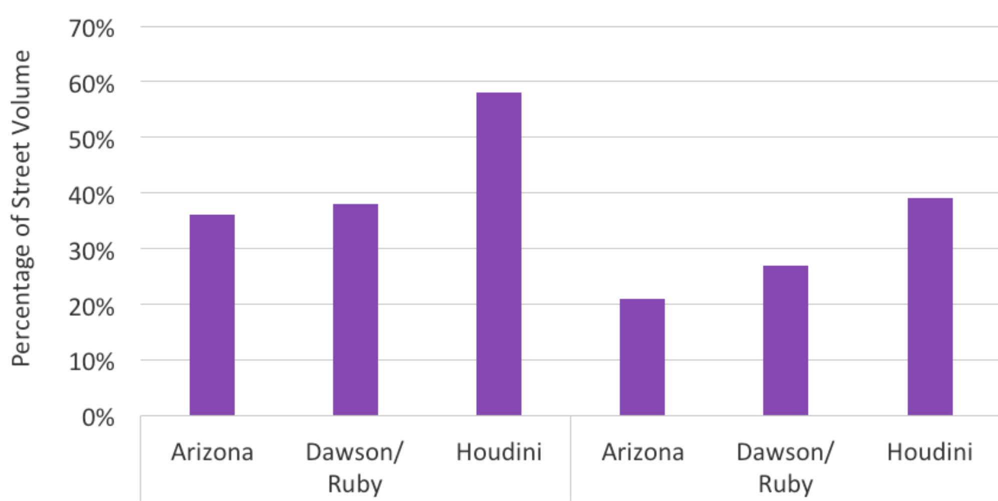


Figure 25: Off-Street parking garage egress and ingress vehicle flow as percentage of street volume across all phases



5.3 High Levels of Unorganized Pedestrian Activity

Pedestrian-vehicle interactions affect traffic operations. We observed high levels of pedestrian activity in the study area, and high pedestrian volumes (400-500 per hour) crossing the street at points where there was no crosswalk.

Figure 26: Distribution of pedestrians crossing street at non-crosswalk locations in the study area

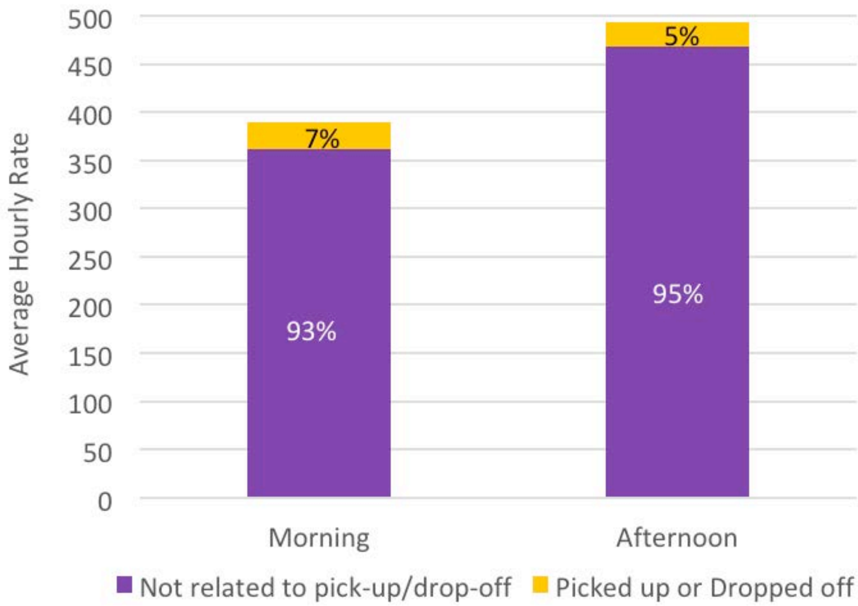
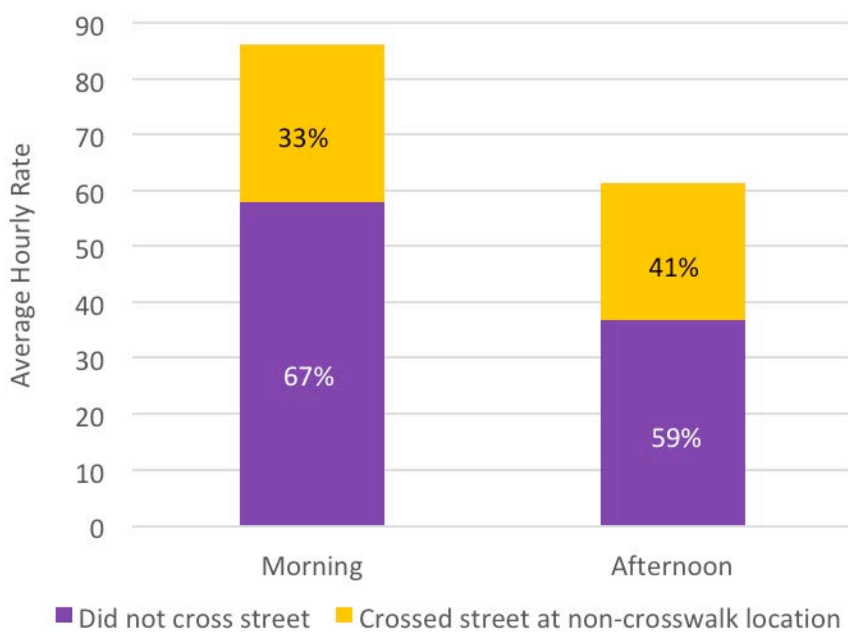


Figure 27: Crossing behavior of passengers being picked up or dropped off at the study blocks



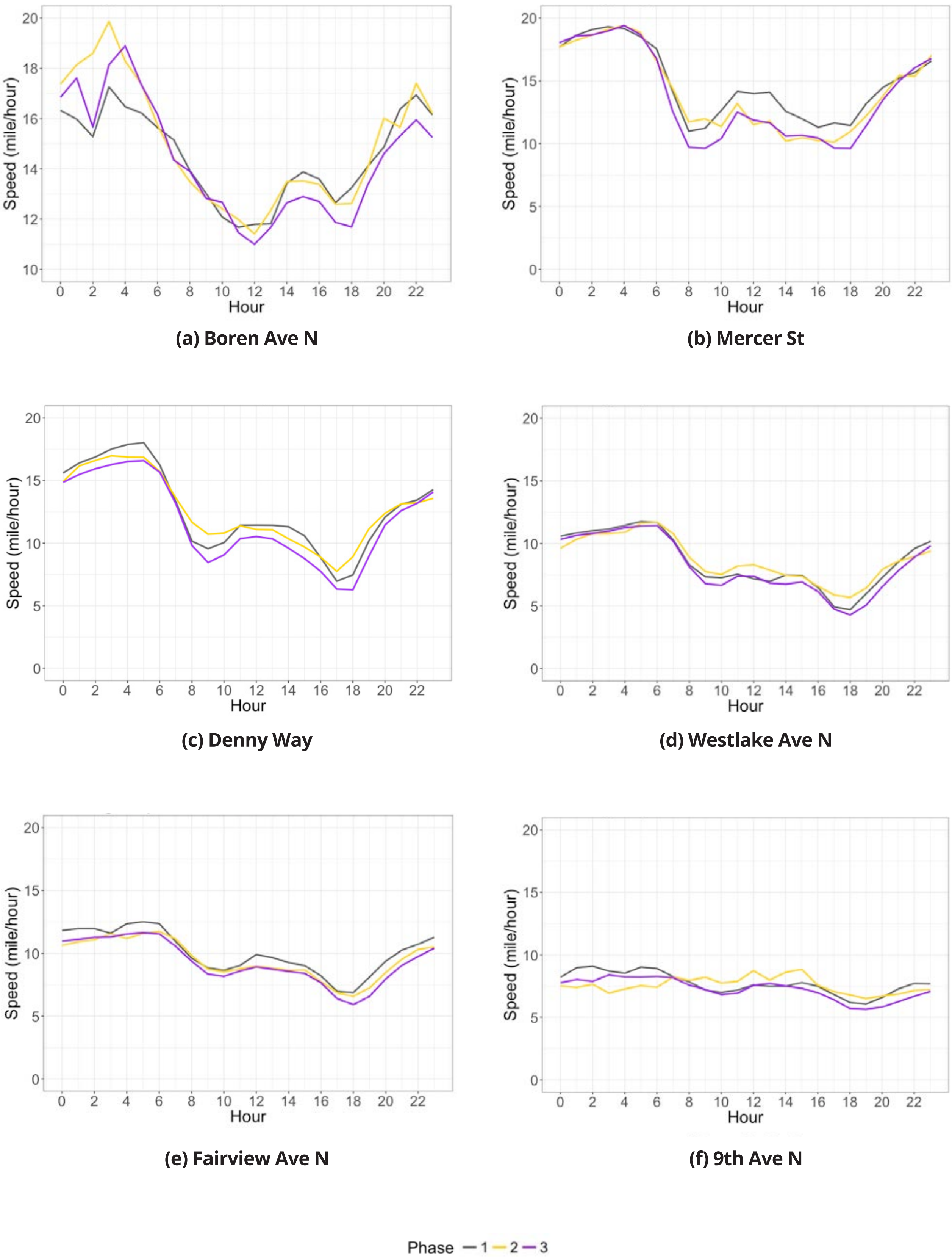
A closer look at the pedestrian activity showed that only 5-7% of those pedestrians were picked up or dropped off by a vehicle (Figure 26). Moreover, an analysis of crossing behaviors for those who were being picked up or dropped off showed that 30-40% of them crossed the street at non-crosswalk locations, as part of the pick-up/drop-off operation (Figure 27).

5.4 Regional Traffic Congestion on Arterials

Figure 28 compares the average vehicle speed profiles for arterials in the proximity of the study area across different study phases. The study area (Boren Ave N) shows a similar speed profile to Denny Way and Mercer Street, which are major arterials (2 and 3 lanes per direction, respectively) with access to the Interstate 5 highway, and perpendicularly intersect with Boren Ave. During the study, we observed these arterials getting very congested during the afternoon peak with spillbacks going onto Boren Ave and sometime causing the queue of vehicles extending up to two blocks south of Mercer St or north of Denny Way, which in turn resulted in deterioration in rule-following and some dangerous driving behavior. The corresponding speed graphs (Figures 28(a), 28(b) and 28(c)) also indicate lower speeds during peak hours and higher speeds during off-peak hours, showing signs of congestion and possible spillbacks from these congested arterials to Boren Ave.

The speed profiles of Westlake Ave N, Fairview Ave N and 9th Ave N are similar to each other and different from that of the study area, with generally lower speeds and less variation across time of day. These three arterials are parallel to Boren Ave and do not intersect with the study area.

Figure 28: Comparison of average vehicle speed across different arterial roads nearby the study area and across study phases.



(a) Boren Ave N

(b) Mercer St

(c) Denny Way

(d) Westlake Ave N

(e) Fairview Ave N

(f) 9th Ave N

6

Conclusion and Recommendations

6 CONCLUSION AND RECOMMENDATIONS

As noted at the beginning of this report, this study focuses on a strategy to manage TNC driver stops when picking up and dropping off passengers with the goal of improving traffic flow in the vehicle-congested and pedestrian-heavy South Lake Union (SLU) neighborhood, home to the main campus of Amazon, the retail company. The two-pronged strategy includes providing additional passenger loading zone (PLZ) spaces and implementing a geofence, which directs ride-hailing drivers and passengers to designated pick-up and drop-off spots on a block.

The aim of providing ample designated pick-up and drop-off spots along the curb was to reduce the frequency with which TNC drivers stop in the travel lane to pick up or drop off passengers and the time they stay stopped there. The findings show a reduction in both in-lane stops and dwell time in the wake of the expanded PLZs and geofencing. In other words, by these measures the strategy was a success.

The study findings do not, however, show the strategy producing a significant impact on traffic safety or roadway travel speed. This is perhaps unsurprising, given that drivers in the study area tend to drive at relatively slow speeds anyway, navigating around high pedestrian and jaywalking volumes, and seem relatively comfortable stopping in the middle of the street for short periods of time. Due to the nature of area traffic, this seems to have relatively little impact on other drivers. Drivers appear to anticipate both this behavior and the high volumes of vehicles moving onto/off the curb and into/out of driveways and alleys.

Of note is the study observation regarding the high volumes of pedestrians crossing the street at points where there was no crosswalk (400-500 an hour on average) and passengers' contribution to that high volume. Passengers picked-up/dropped-off constituted a small fraction (five to seven percent) of those pedestrians, but high rates of passengers (30 to 40 percent) cross the street at non-crosswalk locations.

The study finds that while vehicles picking-up/dropping-off passengers clearly account for a large share of traffic volume in SLU, TNC pick-up and drop-off activity is not the primary cause of congestion. Myriad factors impact neighborhood congestion, including high vehicle volume overall and bottlenecks moving out of the neighborhood onto regional arterials. As researchers observed in the afternoon peak, these bottlenecks cause spillbacks onto local streets. Amazon garages exit vehicles onto streets that then feed into these clogged arterials.

While others can learn from this analysis, this study's findings apply to streets with comparable speed of traffic, mix of roadway users, and street design. Roadways with much higher traffic speeds or different geometric design could be anticipated to produce different results.

Given that research is often conducted with limited time and/or budget, we identify for recommendation three low-cost, high-yield measures that can inform future research: passenger survey, early site visits, and limited field observations. The research team's site visits early in the project were instrumental in identifying the most appropriate variables and measures as well as the means to collect them. Once the study was underway, even a few hours of field observation proved invaluable in enriching qualitative understanding and capturing issues (such as high volumes of unorganized pedestrian crossings) that were not as effectively captured by other means.

Any initiative to manage the use of curbs and roads (by TNC or others) is part of a city's broader transportation policy framework and goals. Whether the strategy this study analyzed is recommended depends on those goals.

The strategy had no observable effect on travel speeds or safety. The research team found the increased PLZ allocation and geofencing strategy reduced dwell times, reduced the number of in-lane pick-ups/drop-offs, increased curb-use compliance, and increased TNC user satisfaction. However, these outcomes will likely encourage commuters to use TNC. Results of the study's passenger survey clearly show that TNC service is attracting passengers who would have otherwise walked or used transit. If the end goal is to reduce traffic congestion, measures to reduce—rather than encourage—TNC and passenger car use as the predominant mode of commuting will yield benefits.

APPENDIX A:
CHANGES MADE BY SDOT IN THE SOUTH LAKE UNION AREA

Table A.1: Inventory of Curb Changes by SDOT in the South Lake Union Area

LOCATION	CHANGE
Boren: Mercer to Republican	• (Both sides) Changed paid parking time limit from 10 hours to 2 hours • (Both sides) Changed PS-VEN to PLZ-VEN at AM and PM times (7-10am and 2-7pm)
Boren: Republican to Harrison	• (East side) Changed paid parking time limit from 10 hours to 2 hours • (East side) Changed PS-VEN to PLZ-VEN at AM and PM times (7-10am and 2-7pm) • (East side) Re-paint striping of angled parking on west side
Boren: Harrison to Thomas	• (Both sides) Changed paid parking time limit from 10 hours to 2 hours • (Both sides) Changed PS-VEN to PLZ-VEN at AM and PM times (7-10am and 2-7pm) • (East side) Changed paid parking to PLZ-VEN at PM peak (3-7pm)
Boren: Thomas to John	• (Both sides) Changed paid parking time limit from 10 hours to 2 hours • (Both sides) Changed PS-VEN to PLZ at AM and PM times (7-10am and 2-7pm)
Harrison: Westlake to Terry	• (North side) Changed paid parking time limit from 10 hours to 2 hours • (North side) Changed PS-VEN to PLZ-VEN at AM and PM times (7-10am and 2-7pm)

PS-VEN: Parking/food truck zone

PLZ-VEN: Passenger load zone/ food truck zone

Figure A.1: Detailed map of changes made by SDOT between Mercer and Republican streets

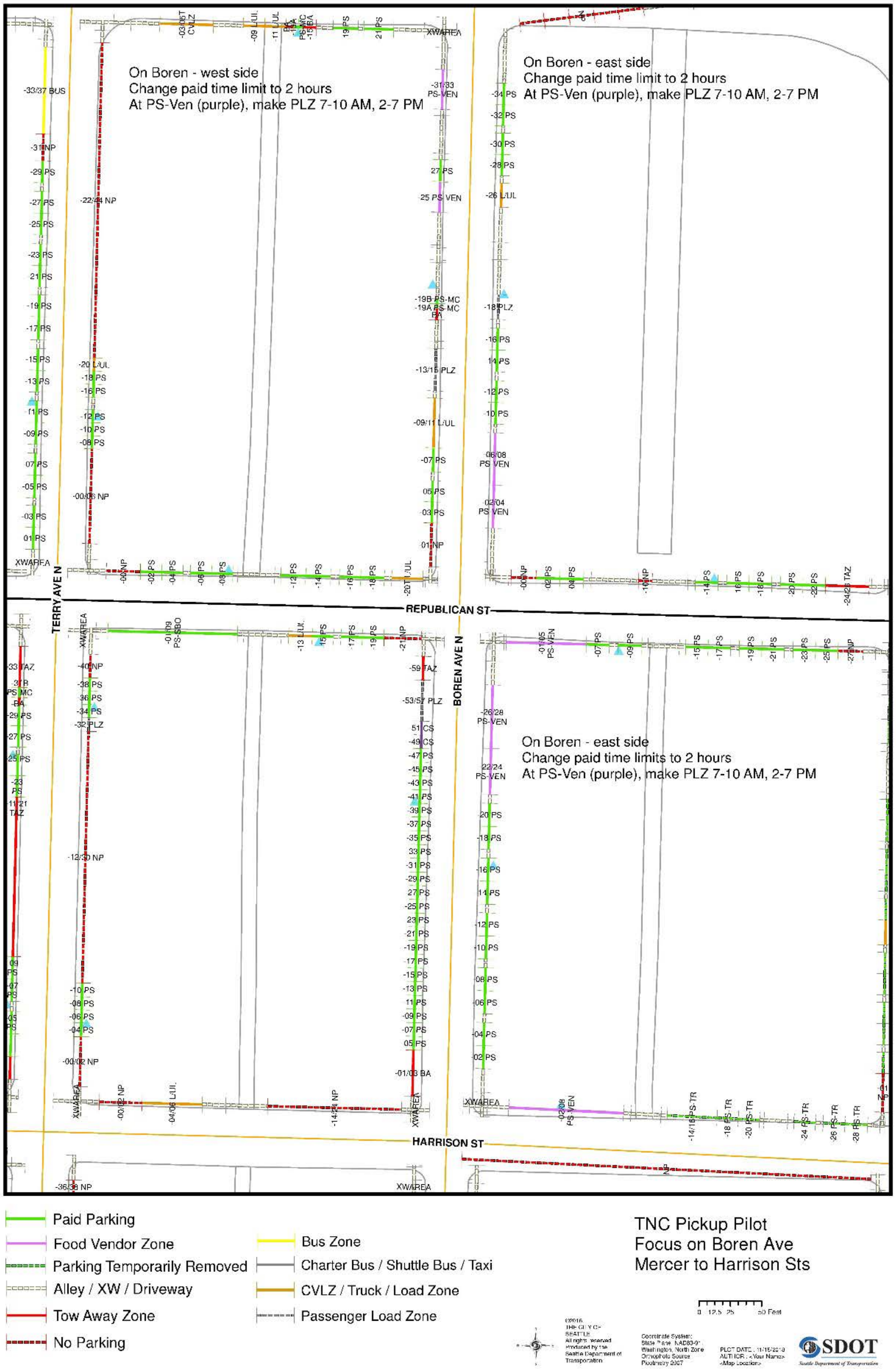
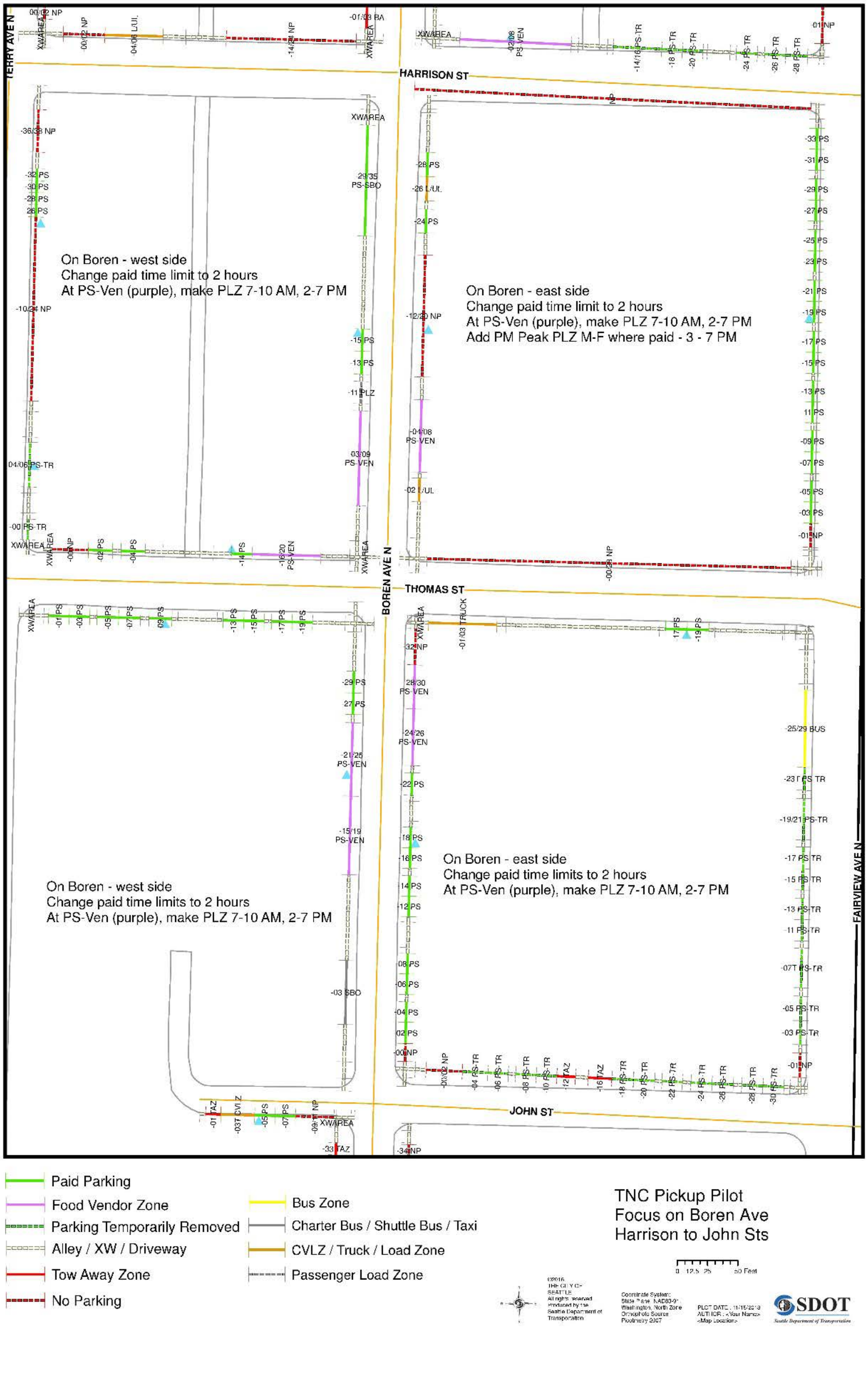


Figure A.2: Detailed map of changes made by SDOT between Mercer and Republican streets



APPENDIX B:
AMAZON'S POSTER SENT OUT TO EMPLOYEES REGARDING THE DESIGNATED PICK-UP/DROP-OFF LOCATIONS

APPENDIX C:
PASSENGER SURVEY (PICK-UP EXAMPLE)

Ride-Hailing Use Travel Survey

University of Washington

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Purpose of the Study

This survey is part of a study by University of Washington researchers to study the people's use of ride-hailing services (e.g. Uber and Lyft). It will take you only 5 minutes to complete the survey.

Cessation of Participation

Your participation in this study is voluntary and you can stop participating at any time if you do not wish to answer a question or for any other reason.

Confidentiality

We will not collect any individual identifiable information. The study records will not be used to put you at any legal risk of harm.

Electronic Consent

Please select your choice below. Clicking on the "Agree" button below indicates that:

- ☐ you understand the information above
- ☐ you voluntarily agree to participate, and have not been pressured to do so
- ☐ you are at least 18 years of age

If you do not wish to participate in the research study, please decline participation by clicking on the " Disagree" button

- ☐ Agree
- ☐ Disagree

Please provide the following information for your ride-hailing trip (e.g. Uber or Lyft) trip from/to South Lake Union.

1. How was your experience with the pick-up for that trip?

- ☐ 6 (Excellent)
- ☐ 5 (Very Good)
- ☐ 4 (Good)
- ☐ 3 (Okay)
- ☐ 2 (Poor)
- ☐ 1 (Awful)

2. Which ride-hailing service did you request for that trip?

- ☐ Private economy ride (Uber X, Lyft)
- ☐ Shared door-to-door ride (Uber Pool, Lyft Shared)
- ☐ Shared with a short walk (Uber Express Pool)
- ☐ Premium/luxury vehicles (Uber Select, Uber Black, Lyft Lux, Lyft Lux Black)
- ☐ Extra Space (Uber XL, Black SUV, Lyft XL, Lux Black XL)

3. How many other riders were matched with? (Select NA if you requested a private ride.)

- ☐ NA (I requested a private ride)
- ☐ 0
- ☐ 1
- ☐ 2
- ☐ 3

4. Where did that trip end? (Enter as city and cross streets)

- ☐ City ______________________________
- ☐ At (Street Name) ____________________ and (Street Name) ____________________

5. Where were you going on that trip?

- ☐ Home
- ☐ Work
- ☐ Personal Business ((bank, doctor appointment, etc.)
- ☐ Recreation/Meal/Social
- ☐ Shopping
- ☐ Other (please specify) ______________________________

6. **If you didn't take ride-hailing (e.g. Uber or Lyft) all the way from your origin to destination, what was the other mode of transportation that you used for your trip?**

- ▢ Public Transit (Bus, Link, Streetcar)
- ▢ Car-share
- ▢ Picked up/dropped off (by a friend or a family member)
- ▢ Drive your personal car
- ▢ Bike
- ▢ Walk
- ▢ NA (It was just ride-hailing)

7. **If ride-hailing (e.g. Uber or Lyft) were not available, how would have you made this trip?**

- ▢ Drive your personal car
- ▢ Being picked up/dropped off (by a friend or a family member)
- ▢ Car-share
- ▢ Public Transit (Bus, Link, Streetcar)
- ▢ Bike
- ▢ Walk

8. **How often do you generally use ride-hailing services (e.g. Uber or Lyft)?**

- ▢ Daily
- ▢ A few times a week
- ▢ Weekly
- ▢ A few times a month
- ▢ Monthly
- ▢ Less than once a month

9. **What is your age? _______**

10. **What is your gender?**

- ▢ Male
- ▢ Female
- ▢ Prefer not to answer

11. Which of the following best described your current job situation?

- ▢ Employed, work outside the home
- ▢ Employed, work from home
- ▢ Unemployed
- ▢ Student
- ▢ Retired
- ▢ Other (please specify) ________

12. What is your personal annual income level?

- ▢ Less than $15,000
- ▢ $15,000 to $29,999
- ▢ $30,000 to $49,999
- ▢ $50,000 to $74,999
- ▢ $75,000 to $99,999
- ▢ $100,000 to $150,000
- ▢ $150,000 to $200,000
- ▢ More than $200,000

13. How many automobiles are available for regular use in your household?

- ▢ 0
- ▢ 1
- ▢ 2
- ▢ 3
- ▢ More than 3

Thank you for participating in our survey!

If you wish to be entered in a raffle drawing for an Apple Watch, please enter your contact information below.

Email (optional): _______

Phone Number (optional): _______

Thank you for your time!

APPENDIX D:
DETAILS ON THE FORMULATION AND ESTIMATION OF THE SPEED REGRESSION MODEL

In this section we report the details of the lognormal regression analysis of speed on traffic volume and other variables affecting traffic flow.

Formulation

The base formulation of the regression model is specified below:

$$ln(v_t) = \alpha_o + \alpha_{geof} 1_{[geof_t]} + \alpha_{curb} 1_{[curb_t]} + \alpha_t t + \beta_{vol}\, vol_t + \beta_{ppd}\, ppd_t + \beta_{ppd:curb}\, ppd_t\, 1_{[curb_t]} + \beta_{ppd:geof}\, ppd_t\, 1_{[geof_t]} + \varepsilon_t$$

where:

v_t	average vehicle speed at time t
vol_t	traffic volume at t
ppd_t	total no. of passenger pick-ups/drop-offs events at t
t	set of indicator variables controlling for time of day
$1_{[geof_t]}$	indicator variable = 1 whenever time t took place when geofencing was implemented (phase 3), 0 otherwise
$1_{[curb_t]}$	indicator variable = 1 whenever time t took place when curb changes were implemented (Phase 2 and 3), 0 otherwise
$\alpha_o, \alpha_{geof}, \alpha_{curb}, \alpha_t$	parameters estimating the free-flow speed under different conditions
$\beta_{vol}, \beta_{ppd}, \beta_t$	parameters estimating the effect of traffic volume and passenger pick-up and drop-off for the baseline condition
$\beta_{ppd:curb}, \beta_{ppd:geof}$	parameters estimating the change in the effect of passenger pick-up and drop-off after the curb changes and the introduction of geofencing
ε_t	random error term

In the above model formulation, we are particularly interested in the following parameters:

- β_{ppd} is the effect of the number of passenger pickup and dropoff in the baseline, i.e. before the curb reallocation and/or geofencing
- $\beta_{ppd} + \beta_{ppd:curb}$ is the effect of the number of passenger pickup and dropoff after the curb changes
- $\beta_{ppd} + \beta_{ppd:geof}$ is the effect of the number of passenger pickup and dropoff after the sigange and the geofencing

Estimation Results

For every 30 minutes, the average vehicle speed was recorded, together with total traffic volume and total number of pick-ups and drop-offs events, during the morning and afternoon peak hours (respectively during 8-10am and 2-6pm), separately for the South Bound (SB) lane and North Bound (NB) lane of the segment of Boren Avenue North between Harrison Street and Thomas Street. Together, the dataset contains 352 observations in total.

We used this data to estimate four different regression models, listed in Table D.1. The models differ by: *(i)* whether all observations are used in the estimation, or whether only SB or NB data is used; *(ii)* whether the variable ppd_t is used in the model, or whether the effect of number pick-ups and drop-offs is accounted separately in the model. In all regression models, we control for time of the day and whether it was raining or not.

Table D.1: Model specification summary

MODEL	DATA USED	NO. OBSERVATIONS	PICK-UP/DROP-OFF
M1	All data	352	No
M2	all data	352	Yes
M3	Only SB data	176	Yes
M4	Only NB data	176	Yes

The regression parameters are estimated using Ordinary Least Square (OLS) method, while the parameter standard error are Heteroskedasticity and Autocorrelation Consistent (HAC) robust estimates. Table D.2 reports the estimates of the coefficients, robust standard errors and p-values for the four regression models.

Table D.2: Estimation results

COEFFICIENT	COEFFICIENT ESTIMATES			
	M1	M2	M3 (NB)	M4 (SB)
α_o	2.803 *** (0.042)	2.809 *** (0.053)	2.763 *** (0.065)	2.845 *** (0.084)
α_{geof}	-0.081 *** (0.030)	-0.073 ** (0.032)	-0.044 (0.046)	-0.060 (0.049)
α_{curb}	0.013 (0.039)	0.006 (0.044)	0.005 (0.068)	0.009 (0.061)
β_{vol}	0.001 (0.0004)	0.001 (0.0005)	0.0002 (0.0004)	0.001 (0.001)
$\beta_{vol-opp}$	-0.002 *** (0.0004)	-0.002 *** (0.0005)	-0.002 * (0.001)	-0.002 *** (0.001)
β_{ppd}	-0.011 *** (0.003)	/	/	/
β_{pick}	/	-0.011 *** (0.004)	-0.007 (0.007)	-0.014 *** (0.005)
β_{drop}	/	-0.012 *** (0.004)	-0.008 * (0.004)	-0.016 *** (0.006)
$\beta_{ppd:curb}$	0.003 (0.003)	/	/	/
$\beta_{pick:curb}$	/	0.004 (0.004)	0.001 (0.007)	0.006 (0.006)
$\beta_{drop:curb}$	/	0.003 (0.003)	-0.001 (0.004)	0.004 (0.005)
$\beta_{ppd:geof}$	0.005 *** (0.002)	/	/	/
$\beta_{pick:geof}$	/	0.004 (0.003)	0.001 (0.003)	0.002 (0.005)
$\beta_{drop:geof}$	/	0.005 ** (0.002)	0.007 ** (0.003)	0.001 (0.003)

*** p-value ≤ 0.001 ; ** p-value ∈ (0.001, 0.01] ; * p-value ∈ (0.01, 0.05]

To predict the effect of the number of passenger drop-off and pick-up events on average speed we use the following formulas:

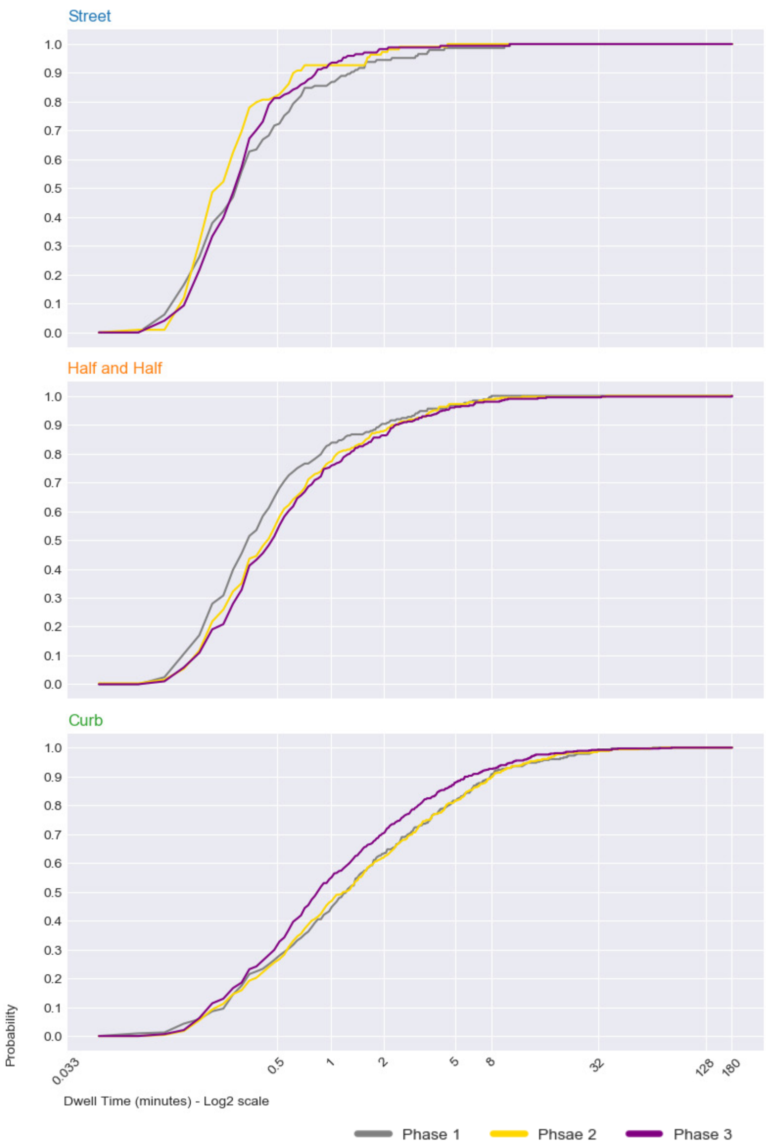
- $\%\Delta v = 100 * [exp(\beta_{ppd} * 10) - 1]$ estimate the percentage of change in average speed caused by an increase in 10 passenger drop-off/pick-up events, before the system changes;
- $\%\Delta v = 100 * [exp((\beta_{ppd} + \beta_{ppd:geof}) * 10) - 1]$ to estimate the percentage of change in average speed caused by an increase in 10 passenger drop-off/pick-up events, after the system changes.

APPENDIX E:
DWELL TIME ANALYSIS FOR PASSENGER PICK-UPS FOR DIFFERENT EVENT LOCATIONS

Pick-up dwell times happening on street and half way between street and curb also showed statistically significant differences (at a less than 5% significance level) between the three phases of study based on a Kolmogorov-Smirnov test.

Pick-ups/Drop-offs happening half way between street and curb were slower in Phase 3 than in Phase 1. Additionally, events happening on street were faster in Phase 2 than in Phase 1.

Figure E.1: Empirical dwell time distribution of passenger pick-ups by stop location for the three phases of study (all three block-faces and bot h directions)



APPENDIX F:
CHI-SQUARE TEST RESULTS FOR COMPLIANCE IN PICK-UP/DROP-OFF BEHAVIORS

The null hypothesis is that there is not a significant difference between the number of on-street versus curb stops across the three phases. However, the p-value results from the chi-square test are very small, which rejects the null hypothesis.

Table E.1: Chi-square Test Results for Compliance in Pick-up Operations

	ON-STREET	CURB (AUTHORIZED AND UN-AUTHORIZED)
Phase 1	145	571
Phase 2	109	826
Phase 3	171	1019
df=2, $\chi 2$=24.099, p-value=5.85E-06		

Table E.2: Chi-square Test Results for Compliance in Drop-off Operations

	ON-STREET	CURB (AUTHORIZED AND UN-AUTHORIZED)
Phase 1	134	712
Phase 2	116	919
Phase 3	192	1127
df=2, $\chi 2$=9.4312, p-value=8.96E-03		

APPENDIX G:
VEHICLE REPRESENTATIVE LENGTH

VEHICLE TYPE	REPRESENTATIVE LENGTH (FT)	REFERENCE
Passenger vehicle, TNC, and Taxi	15	Minge, E. D., Peterson, S., Weinblatt, H., Coifman, B., & Hoekman, E. (2012). *Loop-and length-based vehicle classification: Federal highway administration-pooled fund program [tpf-5 (192)]* (No. MN/RC 2012-33). Minnesota Department of Transportation, Research Services.
Large passenger vehicle	22	2019 Ford Transit Passenger Wagon T-350 148” EL High Roof XL Sliding RH Dr DRW Specs. URL: https://www.thecarconnection.com/specifications/ford_transit-passenger-wagon_2019_t-350-148-el-high-roof-xl-sliding-rh-dr-drw. Accessed on May 20, 2019.
Truck	30	Urban Street Design Guide (2018). National Association of City Transportation (NACTO). https://nacto.org/publication/urban-street-design-guide/design-controls/design-vehicle/. Accessed on May 20, 2019.

APPENDIX H:
ESTIMATION RESULTS OF THE BINOMIAL REGRESSION MODEL OF THE PROBABILITY OF A PICK-UP/DROP-OFF EVENT BEING A CONFLICT

Table H.1 reports the parameter estimates, the standard error and the significance level of the estimates, for the binomial regression model of the probability of a pick-up/drop-off event being a conflict.

Table H.1: Estimation Results

COEFFICIENT	ESTIMATE	STD. ERROR	SIGN
Intercept	-2.486	0.320	***
Volume	0.003	0.003	
Volume (opposite lane)	0.007	0.003	
No. drop-off events	-0.011	0.012	
No. pick-up events	-0.002	0.016	
Rain	0.103	0.105	
Added PLZs	-0.003	0.130	
Added PLZs+Geofencing	0.161	0.108	
*** p-value ≤ 0.001 ; ** p-value ∈ (0.001, 0.01] ; * p-value ∈ (0.01, 0.05]			

APPENDIX I:
RESULTS OF ORDINAL LOGIT MODEL FOR PASSENGER SATISFACTION

Since satisfaction was defined as an ordered variable (in categories from Excellent to Awful), we applied an ordinal logit model to analyze the data and test the significance of changes on passenger satisfaction (the outcome variable).

Tables I.1 shows the results for a single-variate model, where the only predictor is study phase, and Table I.2 presents the results for a multivariate model where in addition to the study phase, other predictor variables are also considered. As can be seen from the t-values, in both models the phase variable was significant.

Table I.1: Analysis results for the single-variate model

COEFFICIENTS:	VALUE	STD. ERROR	T-VALUE
Phase: 3	0.6462	0.3515	1.838
INTERCEPTS:	**VALUE**	**STD. ERROR**	**T-VALUE**
Aweful|Poor	-4.4441	1.0104	-4.3983
Poor|Okay	-2.4397	0.4202	-5.8058
Okay|Good	-1.3708	0.307	-4.4651
Good|Very Good	-0.7057	0.2808	-2.5133
Very Good|Excellent	0.4819	0.2776	1.7363
Residual Deviance	311.818		
AIC	323.818		
Log Likelihood	-155.91	(df=6)	

Table I.2: Analysis results for the multi-variate model

COEFFICIENTS:	VALUE	STD. ERROR	T-VALUE
Pick-up	0.8901	0.6827	1.304
Phase: 3	0.6954	0.3994	1.741
Purpose: Work	2.5395	0.8072	3.146
Purpose: PersonalBusiness	-1.0555	0.7322	-1.442
Purpose: Meal/Social	1.2833	0.5984	2.145
Usage Frequency	-0.1612	0.1407	-1.145
Annual Income > $100K	-0.7118	0.4812	-1.479
No Mode Connection (Only RH)	-1.3035	0.4971	-2.622
Transfer to/from Transit	0.9767	0.7489	1.304
INTERCEPTS:	**VALUE**	**STD. ERROR**	**T-VALUE**
Aweful|Poor	-5.3257	1.4676	-3.6288
Poor|Okay	-3.1906	1.1166	-2.8574
Okay|Good	-1.8718	1.0495	-1.7836
Good|Very Good	-1.0118	1.0365	-0.9762
Very Good|Excellent	0.5543	1.034	0.536
Residual Deviance	266.9282		
AIC	294.9282		
Log Likelihood	-133.464	(df=14)	

APPENDIX J:
CONSTRUCTION ACTIVITIES IN THE PROXIMITY OF THE STUDY AREA

CONSTRUCTION SITE	WORK AND CLOSURE DESCRIPTION	DATES
John St between Boren Ave N and Fairview Ave N		Dec 3-7, 2018 9am-3pm
Terry Ave N between Harrison St and Thomas St	One travel lane closed.	Dec 3-7, 2018 9am-3pm
Intersection of Boren Ave N and Harrison St	ADA ramp & Sidewalk. Two-way directional traffic maintained during off peak hours. Two travel lanes maintained during peak hours.	Dec 17-19, 2018 9am-3pm
Intersection of Boren Ave N and Harrison St	HMA & Back-ups. Two-way directional traffic maintained during off peak hours. Two travel lanes maintained during peak hours.	Dec 18-21, 2018 9am-3pm
Intersection of Thomas St and Terry Ave N	HMA & Back-ups. Directional traffic maintained with flaggers on Thomas. NB Terry maintained.	Dec 18-21, 2018 9am-3pm
Harrison St between Boren Ave N and Fairview Ave N	HMA & Back-ups. WB Harrison closed.	Dec 18-21, 2018 9am-3pm

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