Freight and Transit Lane Case Study
Final Report

Urban Freight Lab
Supply Chain Transportation & Logistics Center
University of Washington
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EXECUTIVE SUMMARY

The Seattle Department of Transportation (SDOT) engaged the Urban Freight Lab at the Supply Chain Transportation and Logistics Center at the University of Washington to conduct research on the impacts of a freight and transit (FAT) lane that was implemented in January 2019 in Seattle. To improve freight mobility in the City of Seattle and realize the objectives included in the city's Freight Master Plan (FMP), the FAT lane was opened upon the closing of the Alaskan Way Viaduct.

The objective of this study was therefore to evaluate the performance and utilization of the FAT lane. Street camera video recordings from two separate intersection locations were used for this research. Vehicles were categorized into ten different groups, including drayage with container and drayage without container, to capture their different behavior. Drayage vehicles are vehicles transporting cargo to a warehouse or to another port. Human data reducers used the street camera videos to count vehicles in those ten designated groups.

The results of the traffic volume analysis showed that transit vehicles chose the FAT lane over the general purpose lane at ratios of higher than 90 percent. By time of day, transit vehicle volumes in the FAT lane followed a different pattern than freight vehicles. Transit vehicle volumes peaked around afternoon rush hours, but freight activity decreased during that same time. Some freight vehicles used the FAT lane, but their ratio in the FAT lane decreased when bus volumes increased. The ratio of unauthorized vehicles in the FAT lane increased during congestion.

Further analysis described in this report included a multinomial logistic regression model to estimate the factors influencing the choice of FAT lane over the regular lane. The results showed that lane choice was dependent on day of week, time of day, vehicle type, and location features. Density, as a measure of congestion, was found to be statistically insignificant for the model.

INTRODUCTION

Motivation

Under the scope of its Freight Master Plan (FMP), the Seattle Department of Transportation (SDOT) is attempting to develop solutions to address the challenges of freight mobility. As the population in Seattle increases, so does the demand for goods and services in the city. To support Seattle's burgeoning economy, the city aims to maintain and improve truck freight mobility.

In January 2019, SDOT allocated the curbside lane on S Alaskan Way between S Jackson St & S King St (north to south) to transit buses and freight vehicles, thereby implementing a freight and transit (FAT) lane. This project aligned with SDOT's strategies outlined in the FMP to explore and test the use of truck-only lanes. The research findings presented in this report shed light on the FAT lane's performance toward achieving city goals, and can be used to guide the development of future FAT lane projects.

Research Scan

A research scan revealed little evidence of the existence of freight and transit lanes implemented in urban areas. While studies and pilot tests have looked at the exclusive allocation of road space to different types of uses (transit, personal, freight), studies combining transit and freight have been minimal.

One similar pilot study occurred in Norwich, United Kingdom. The city conducted a six-month pilot test on urban freight deliveries by allowing low-emission heavy goods vehicles in the bus-cycle lane. Norwich has a compact urban area with a radial pattern of road corridors. The project aimed to promote the use of low-emission vehicles and mitigate the negative effects of urban freight on other users in the city. Only heavy goods vehicles that met low emission, clean energy standards and that were associated with the Norwich Freight Consolidation Center could use the lane. The Consolidation Center vehicle drivers were trained on how and when to drive in the bus lane.

After the six-month experiment, the researchers found the following:

- Drivers could save 2-4 minutes of time per trip for peak-time journeys, which were 25 minutes on average.
- Usage of the bus lane at off-peak times showed little or no time savings.
- Less fuel consumption and emissions resulted from the time savings.
- The width of the existing bus lanes was a barrier to implementing the measure, so that only Consolidation Center vehicles were allowed to use the bus lanes [1].

We found more examples of studies of bus-only or truck-only lanes. Because the main objectives of this project were to improve freight mobility in urban areas and to mitigate the negative impacts of urban deliveries, the scan focused on examples of freight-only lanes (as opposed to bus-only lanes) and studies on the measurement of their performance.

The State Department of Highways and Public Transportation (SDHPT) in Texas evaluated the potential benefits and feasibility of exclusive truck facilities (ETF) along selected Interstate highways. The success metrics used to measure the performance were as follows:

- level of service (LOS), evaluated at each half-mile segment of the selected highway, with and without trucks
- volume-to-capacity (V/C) ratio, quality of total traffic flow, and the change after the trucks had been removed.

The results showed that exclusive truck lanes had positive changes on LOS and V/C only when truck volumes were higher than 30 percent of vehicular traffic, peak hour volumes exceeded 1,800 vehicles per lane-hour, and off-peak volumes exceeded 1,200 vehicles per lane-hour [2].

Parsons et. al. conducted high-occupancy vehicle and truck-only toll feasibility studies in the Atlanta region to investigate the potential benefits of truck-only-toll (TOT) facilities. TOT lanes are highway lanes that are reserved for the use of commercial vehicles, primarily trucks and buses. The commercial vehicles can choose to pay a fee to use the lanes, or they can continue to use general purpose lanes. The study found the following when TOT facilities were used:

- Total vehicle hours traveled were reduced, with a negligible change in vehicle miles traveled.
- Trucks could save a significant amount of time.
- Congestion in the general-purpose lanes improved significantly [3].

A study at the Florida State University used VISSIM simulation analysis to account for truck restrictions on urban arterials in the left, middle, and right lanes. The study used no-restriction as a control group. These facilities were not truck exclusive; the lane was shared with other vehicle types. The results suggested that when trucks were restricted to the right lane (compared to no restriction), then

- travel time decreased
- passenger cars and trucks had higher average speeds
- the average queue length at the intersections was slightly lower.

The study also found that restricting trucks to the left or middle lane resulted in a greater number of lane changes [4].

Background

DESCRIPTION OF STUDY AREA

A major thoroughfare in Seattle, the Alaskan Way Viaduct, was closed on January 11, 2019, significantly reducing capacity on the already congested road network in greater downtown Seattle. The City of Seattle Department of Transportation, in partnership with the Washington State Department of Transportation (WSDOT), temporarily installed two blocks of a freight and transit (FAT) lane on Alaskan Way to improve freight and transit access to commercial and industrial areas in the city.

The FAT lane was in the curb lane only, on southbound Alaskan Way at street level. The two-block segment was between S Main St and S King Street, allowing freight vehicles to access Port of Seattle terminals, Harbor Island, the SoDo (South of Downtown) district, and the surrounding industrial areas more easily.

Figure 1. The location on the map and signage for the FAT lane

PURPOSE AND SCOPE

The goal of this project was to evaluate the operational costs and benefits of the FAT lane implementation. The key research questions (RQ) assessed in this report were as follows:

RQ1. Did the FAT lane attract heavy freight vehicles?

RQ2. Were negative implications of the FAT lane implementation observed in the study area?

RQ3. What are desirable characteristics to look for in future FAT lane test case study sites?

RQ4. What are some additional considerations for future FAT lane case studies?

DATA COLLECTION

The data used for this study were provided in video format by SDOT. The street camera recordings were from the southwest end of the section at two intersection locations overlooking the FAT lane.

Two sets of data were taken from two separate locations: S Alaskan Way and S Jackson St, and S Alaskan Way and S King St. The recordings were dated January 24 through 30, 2019 (24-hour video recordings), covering a full week. Ten videos were missing, all located at S Alaskan Way and S Jackson St.

Additional data to be used as a control group could not be included in the analysis because the videos showed a construction site on the roadway. The data were dated October 2 through 3, 2018, located at S Alaskan W and Jackson St.

Figure 2 shows the S Alaskan Way and S Jackson St intersection and the FAT lane. Two lanes for each direction are seen on Alaskan Way at street level. The Alaskan Way Viaduct, which was closed at the time, is in the field of view.

Figure 2: Video screenshot from S Alaskan Way and S Jackson St

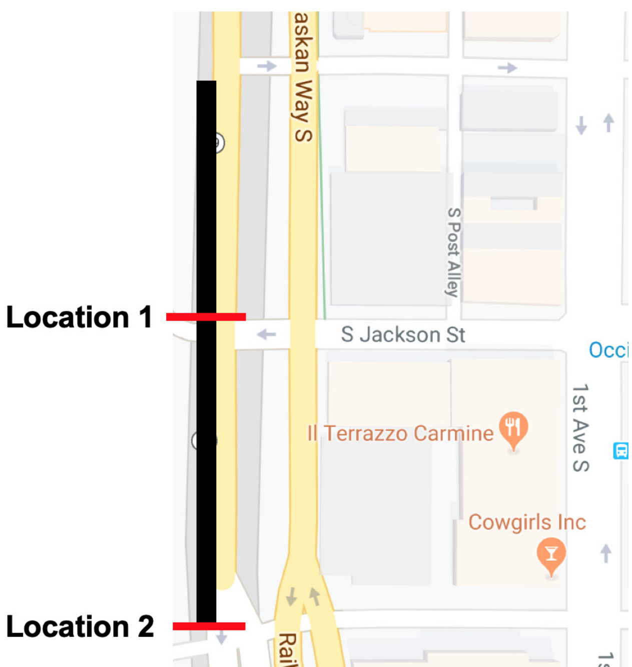
Figure 3 shows the S Alaskan Way and S King St intersection. Two lanes in each direction on S Alaskan Way and the FAT lane (right-most lane) are seen from this side view. The camera view includes the extension of King St entering the port.

Figure 3: Video screenshot from S Alaskan Way and S King St

Figure 4 shows the camera locations:

- Location 1: S Alaskan Way and S Jackson St
- Location 2: S Alaskan Way and S King St

Figure 4: Map of the area



METHODOLOGY

This section describes the vehicle categories, experimental procedure, and density analysis used to evaluate the impact of the FAT lane.

Vehicle Typology

Ten separate vehicle categories were developed so that separate freight, transit, and other road users could be analyzed (see Table 1). Because the FAT lane also supported the services of the port, drayage vehicles were given their own category separate from other trucks. Table 1 shows for each vehicle category's authorization to use the FAT lane. The categories that were not authorized to use the FAT lane will be referred as violators.

Table 1: Types of vehicles across ten vehicle categories

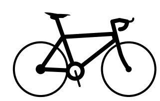
VEHICLE CATEGORY	DEFINITION	AUTHORIZATION ON THE FAT LANE	VISUAL
Bus/Transit	Vehicles manufactured as traditional passenger-carrying buses that are used only for public transportation. They are operated by licensed professional bus drivers on fixed routes.	Authorized	
Bicycles		Authorized	
Truck/Freight: Drayage with container	Trucks consisting two or more frames (trailer or multi trailer) in which the pulling unit is a tractor car that pulls a container (a large metal box in which goods are carried as one unit).	Authorized	
Truck/Freight: Drayage with-out container	Trucks used for drayage purposes without a container (tractor unit or tractor carrying a chassis).	Authorized	
Truck/Freight: Construction and waste	Trucks used for waste management and construction purposes.	Authorized	
Truck/Freight: Others	Single-unit trucks used for goods transport, general commercial activities and/or other, not including drayage trucks.	Authorized	
Truck/freight: Work vans	Pick-ups used for commercial purposes and work vans.	Not Authorized	

Table 1 Continued

VEHICLE CATEGORY	DEFINITION	AUTHORIZATION ON THE FAT LANE	VISUAL
Passenger car and other transit	Sedans, coupes, SUVs, mini-vans, pick-ups manufactured primarily to carry passengers. Vehicles manufactured as traditional passenger-carrying buses (e.g., charter bus, coach bus, school bus, short bus) with a minimum seating capacity of ten people. School, public, private, or commercial passenger-carrying buses and passenger vans, excluding public transit.	Not Authorized	
Emergency vehicles	Vehicles used by emergency response teams (e.g., fire trucks, ambulances, and police cars).	Authorized	
Other vehicles	All the others - All two- or three-wheeled motorized vehicles, vehicles designed for recreation or camping, and vehicles that fail to be identified.	Not Authorized	

Methodology for Vehicle Counts

Traffic flow, the total number of vehicles, was estimated by converting the video into counts of vehicles. Human data reducers watched the videos and produced manual counts.

The vehicle counting was performed for two lanes at each location: the FAT lane and the regular travel lane. The right turners on the FAT lane were counted as a separate group. All right turners were permitted to use the FAT lane (see Figure 5), regardless of their vehicle type. The number of vehicles turning right in the FAT lane were counted separately so that they could be distinguished from violators and be excluded from the data to be used in the analysis.

Figure 5: The signage at the intersection of S Alaskan Way and S Jackson St

The white stop bar on each approach to the intersection was determined to be the boundary for the counts. Humans entered one count for each vehicle once it passed through the white stop bar (see Figures 6 and 7). This decision was necessary to eliminate the ambiguity caused by lane changes and U-turns. The total number of vehicles passing through the boundary, during each 15-minute interval, was recorded as a single number on the data collection spreadsheet.

Figure 6: Video screenshot from S Alaskan Way and S Jackson St

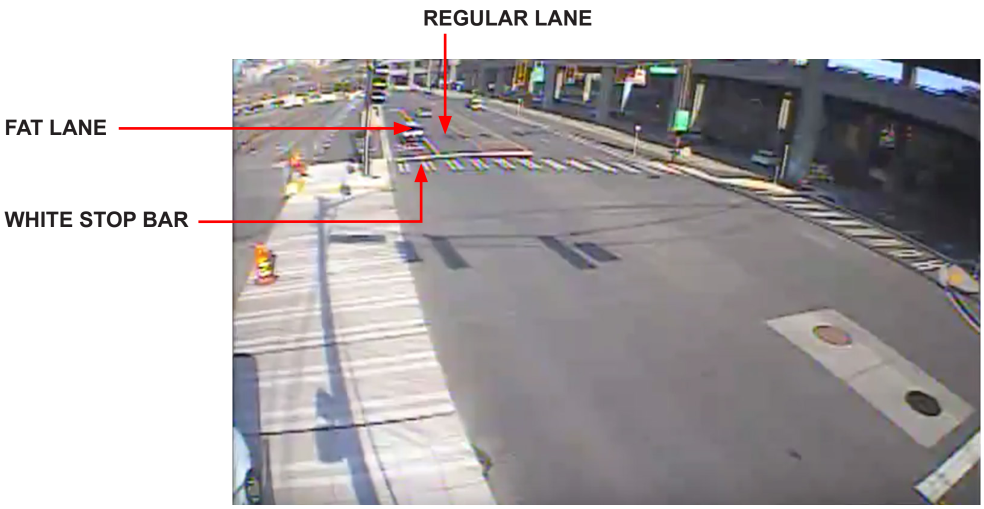


Figure 7: Video screenshot from S Alaskan Way and S King St

Density Analysis

In order to examine how congestion might impact lane choice, the time periods of congestion were identified by using density analysis. Density is defined as the number of vehicles per unit link length. The purpose of this density analysis was to find the congested time intervals.

January 25, 2019, was chosen for sampling for each location.

Screenshot images were taken every 15 minutes from the video recordings. The numbers of vehicles in the FAT and regular lanes were counted. To normalize between two locations, the vehicle counts were divided by the link length to obtain density measures, k_i in units of vehicles per lane-pillars.

The density measures, k_i were averaged over each hour to obtain a density measure for the hour, since instantaneous measures could not be used to define time intervals. A moving average was employed as a data smoothing technique to reduce the noise in the data set and to allow important patterns to stand out. The simple moving average (3) calculated the arithmetic mean over three time periods: the previous, the next, and the data point itself.

The smoothed density values were sorted to find the hours that had the highest three values. Table 2 shows the hours that had highest three density values in each lane, shown in bold. Table 3 shows the peak hours determined for each lane, and the congested times were the union of peak hours in the FAT and regular lanes.

Table 2: Hourly density values for two locations

HOUR	S ALASKAN WAY & S JACKSON ST				S ALASKAN WAY & S KING ST			
	FAT LANE		REGULAR LANE		FAT LANE		REGULAR LANE	
	DENSITY (k_i)	SMOOTHED VALUES	DENSITY (k_i)	SMOOTHED VALUES	DENSITY (k_i)	SMOOTHED VALUES	DENSITY (k_i)	SMOOTHED VALUES
0	0.143	NA	0.143	NA	0.000	NA	0.000	NA
1	0.000	0.048	0.000	0.048	0.000	0.000	0.400	0.133
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.133
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.143	0.000	0.095	0.000	0.000	0.000	0.067
5	0.429	0.143	0.286	0.238	0.000	0.000	0.200	0.467
6	0.000	0.143	0.429	0.667	0.000	0.000	1.200	0.933
7	0.000	0.048	1.286	0.714	0.000	0.000	1.400	1.200
8	0.143	0.238	0.429	1.190	0.000	0.067	1.000	1.467
9	0.571	0.286	1.857	1.381	0.200	0.067	2.000	1.733
10	0.143	0.381	1.857	1.762	0.000	0.067	2.200	1.733
11	0.429	0.476	1.571	1.667	0.000	0.267	1.000	1.600
12	0.857	0.619	1.571	1.524	0.800	0.267	1.600	1.533
13	0.571	0.762	1.429	1.714	0.000	0.267	2.000	2.133
14	0.857	0.810	2.143	2.000	0.000	0.133	2.800	2.800
15	1.000	0.857	2.429	2.476	0.400	0.133	3.600	**3.200**
16	0.714	0.762	2.857	**2.714**	0.000	**0.400**	3.200	**3.200**
17	0.571	**1.000**	2.857	**2.667**	0.800	**0.400**	2.800	**2.867**
18	1.714	**0.952**	2.286	**2.286**	0.400	**0.400**	2.600	2.133
19	0.571	**0.810**	1.714	1.381	0.000	0.133	1.000	1.200
20	0.143	0.238	0.143	0.714	0.000	0.000	0.000	0.333
21	0.000	0.048	0.286	0.238	0.000	0.000	0.000	0.400
22	0.000	0.000	0.286	0.190	0.000	0.000	1.200	0.533
23	0.000	NA	0.000	NA	0.000	NA	0.400	NA
Average	**0.369**	**0.398**	**1.077**	**1.167**	**0.108**	**0.118**	**1.275**	**1.355**

Table 3: Congested times for both locations

LOCATION	LANE	TIMES WHEN THE HIGHEST DENSITY IS OBSERVED (24 HR FORMAT)	CONGESTED TIMES (24 HOUR FORMAT)
S Alaskan Way & S Jackson St	FAT Lane	17-18, 18-19, 19-20	16-20
S Alaskan Way & S Jackson St	Regular Lane	16-17, 17-18, 15-16	
S Alaskan Way & S King St	FAT Lane	16-17, 17-18, 18-19	15-19
S Alaskan Way & S King St	Regular Lane	16-17, 15-16, 17-18	

The most congested times were observed during the afternoon rush at both locations. The densities during congestion were at least two times the daily averages in both the FAT and regular lanes.

ANALYSIS AND KEY FINDINGS

RQ1. Did the FAT lane attract heavy freight vehicles?

This section compares the volumes of vehicles traveling through intersections at the two count locations.

1. WHAT WAS THE BREAKDOWN OF VEHICLE VOLUME IN THE FAT LANE BY VEHICLE TYPE?

The vehicle volumes in each lane are summarized in tables 4 and 5. The highest share of vehicles in the FAT lane at both locations comprised passenger cars, constituting 50 percent and 30 percent of the total vehicle volume in each lane, respectively.

Construction and waste vehicles had significantly higher volumes than any other truck/freight vehicle categories in the FAT lane at both locations, accounting for 11 percent and 21 percent of the vehicle volumes in each FAT lane, respectively.

Table 4: Traffic volumes by vehicle type at S Alaskan Way and S Jackson St

	S ALASKAN WAY & S JACKSON ST					
	FAT LANE		REGULAR LANE		TOTAL	
VEHICLE TYPE	VOLUME	PERCENT OF TOTAL	VOLUME	PERCENT OF TOTAL	VOLUME	PERCENT OF TOTAL
Bicycles	689	14%	38	0%	727	1%
Bus/Transit	702	14%	29	0%	731	1%
Emergency Vehicles	1	0%	57	0%	58	0%
Other vehicles	78	2%	481	1%	559	1%
Passenger/Car & Other transit	2514	50%	46914	92%	49428	88%
Truck/freight: Construction& waste	530	11%	279	1%	809	1%
Truck/freight: Drayage with container	39	1%	120	0%	159	0%
Truck/freight: Drayage without container	20	0%	46	0%	66	0%
Truck/freight: others	269	5%	1411	3%	1680	3%
Truck/freight: Work vans	188	4%	1536	3%	1724	3%
Total	**5030**		**50911**		**55941**	

Table 5: Traffic volumes by vehicle type at S Alaskan Way and S King St

VEHICLE TYPE	S ALASKAN WAY & S KING ST					
	FAT LANE		REGULAR LANE		TOTAL	
	VOLUME	PERCENT OF TOTAL	VOLUME	PERCENT OF TOTAL	VOLUME	PERCENT OF TOTAL
Bicycles	359	11%	80	0%	439	1%
Bus/Transit	782	25%	25	0%	807	1%
Emergency Vehicles	5	0%	83	0%	88	0%
Other vehicles	29	1%	484	1%	513	1%
Passenger/Car & Other transit	960	30%	52236	92%	53196	89%
Truck/freight: Construction& waste	670	21%	618	1%	1288	2%
Truck/freight: Drayage with container	52	2%	152	0%	204	0%
Truck/freight: Drayage without container	20	1%	48	0%	68	0%
Truck/freight: others	169	5%	885	2%	1054	2%
Truck/freight: Work vans	136	4%	1972	3%	2108	4%
Total	**3182**		**56583**		**59765**	

2. WHAT PERCENTAGE OF VEHICLES USED THE FAT LANE VERSUS THE GENERAL TRAVEL LANE BY VEHICLE TYPE?

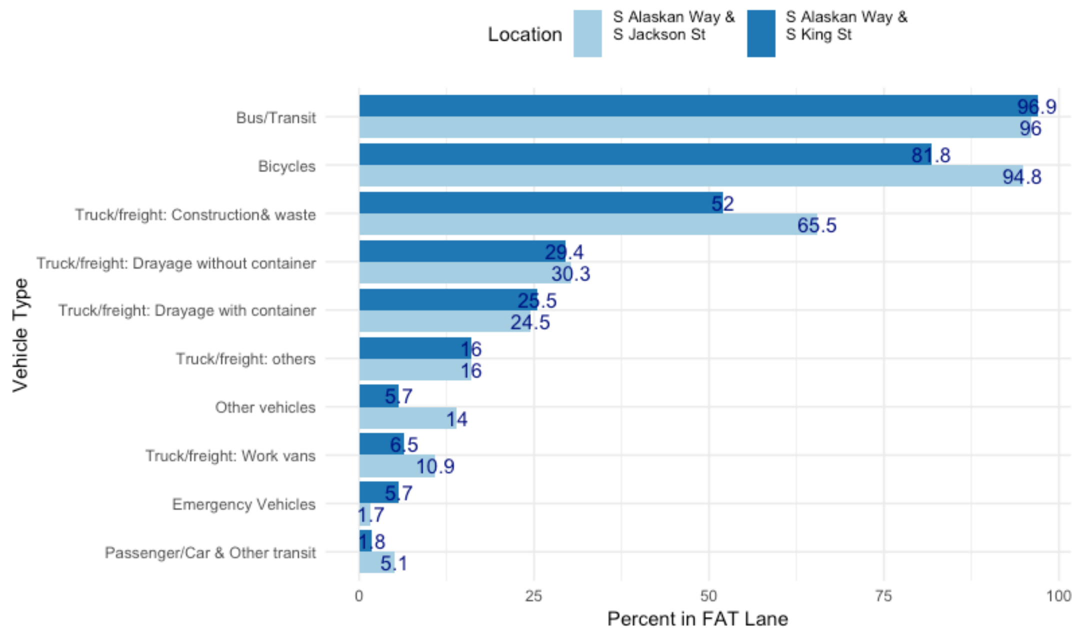
To assess the utilization of the FAT lane, the metric "Percent in FAT" was introduced. This parameter showed the ratio of vehicles in the FAT lane over the total number of vehicles.

$$Percent\ in\ FAT = \frac{Vehicle\ count\ in\ FAT\ lane}{Sum\ of\ vehicle\ count\ in\ FAT\ and\ regular\ lane} * 100$$

Figure 8 shows the percentages in the FAT lane, calculated for each vehicle type. As can be seen in Figure 8,

- The FAT lane was highly utilized by transit buses and bicycles.
- At both locations, transit vehicles used the FAT lane over 95 percent of the time. This is particularly important, showing that authorizing freight vehicles to use the bus-only lane did not impact transit lane choice.
- Construction and waste vehicles used the FAT lane much more frequently than other heavy goods freight vehicles. They chose the FAT lane over the regular lane 52 percent and 65.5 percent of the time for each location, which were much higher ratios than those for drayage without container vehicles (29.4 percent and 30.3 percent) and drayage with container vehicles (25.5 percent and 24.5 percent).
- Passenger vehicles chose the FAT lane 1.8 percent and 5.1 percent of the time at locations 1 and 2, respectively. Because of a high volume of passenger cars, they constituted 50 percent and 30 percent of total volume at each FAT lane location, respectively.

Figure 8: Percentage in the FAT lane by vehicle type

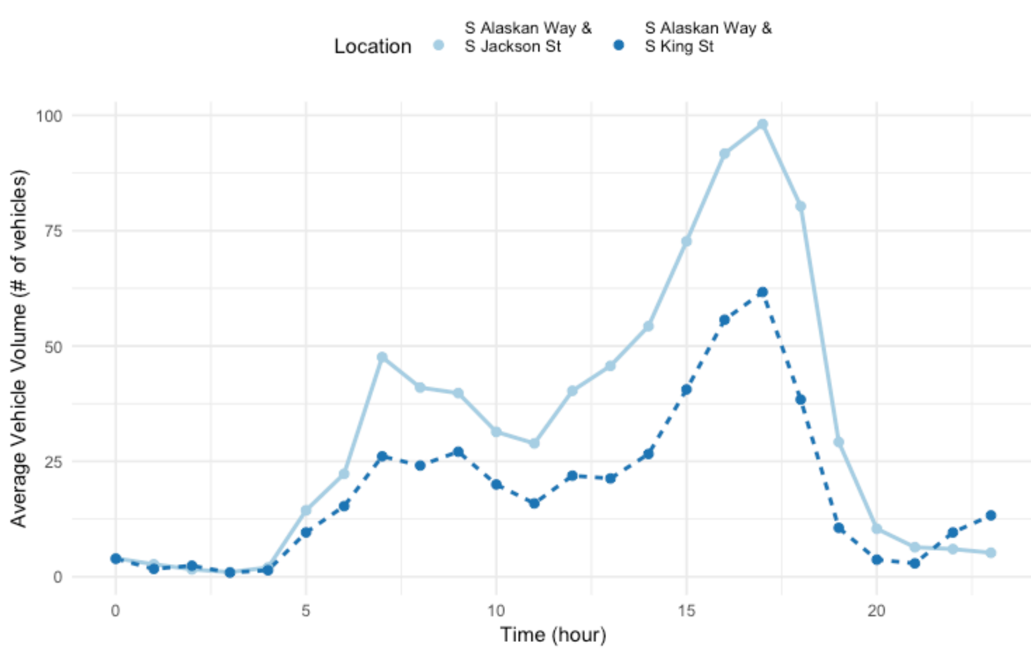


3. WHAT WAS THE VEHICLE VOLUME IN THE FAT LANE BY TIME OF DAY?

The vehicle counts in the FAT lane were accumulated for each hour and averaged over the week to obtain average daily vehicle volume by time of day, hourly. This was helpful to determine daily trends and to identify the times with the highest volumes.

Figure 9 shows the average hourly vehicle volumes over 24 hours in a day for the two locations. At both locations, there was an increase in vehicle volume between 1:00 pm and 5:00 pm, followed by a decrease between 5:00 pm and 9:00 pm.

Figure 9: Average vehicle volumes by time of day

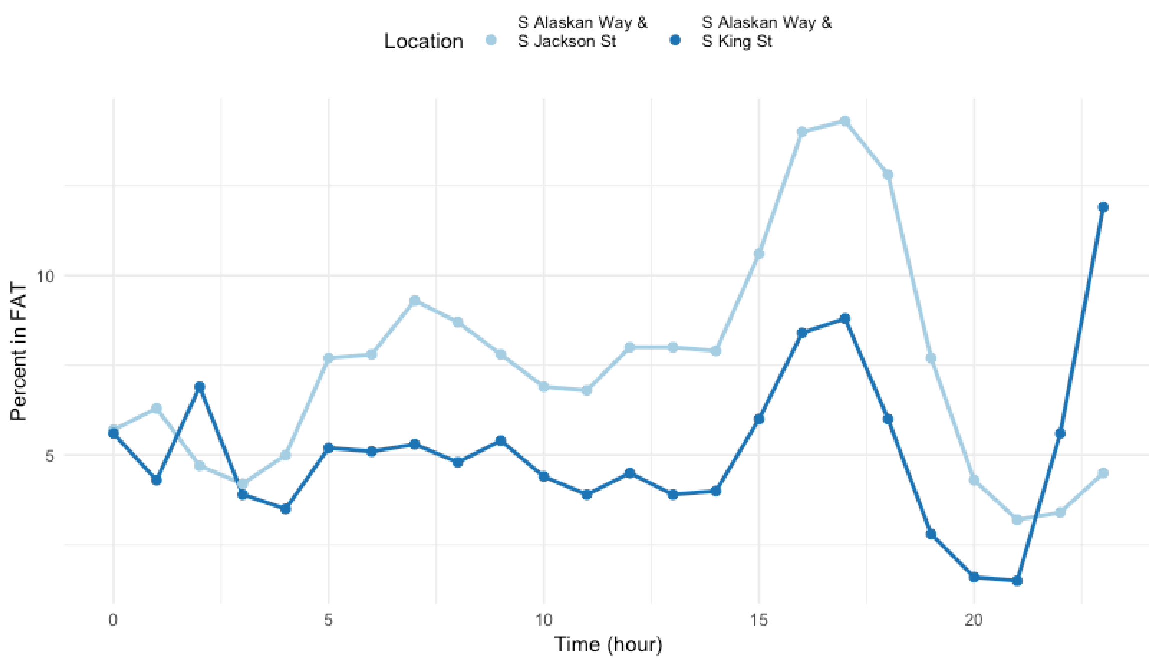


4. WHAT PERCENTAGE OF VEHICLES USED THE FAT LANE VERSUS THE GENERAL TRAVEL LANE BY TIME OF DAY?

To scale the hourly volume data, the volume in the regular lane was used as a baseline. The percentage in the FAT lane parameter was again used.

Figure 10 shows changes in the percentage in the FAT lane parameter over 24 hours. The percentage in the FAT lane showed an increasing trend after 2:00 pm until 5:00 pm and a decreasing trend between 5:00 pm and 9:00 pm. A similar pattern is observed in Figure 9 for average vehicle volumes. The percentage in the FAT lane ratios were 8 percent and 4 percent at 2:00 pm for the two locations, respectively, but they rose to 14.3 percent and 8.8 percent at 5:00 pm as vehicle volumes increased.

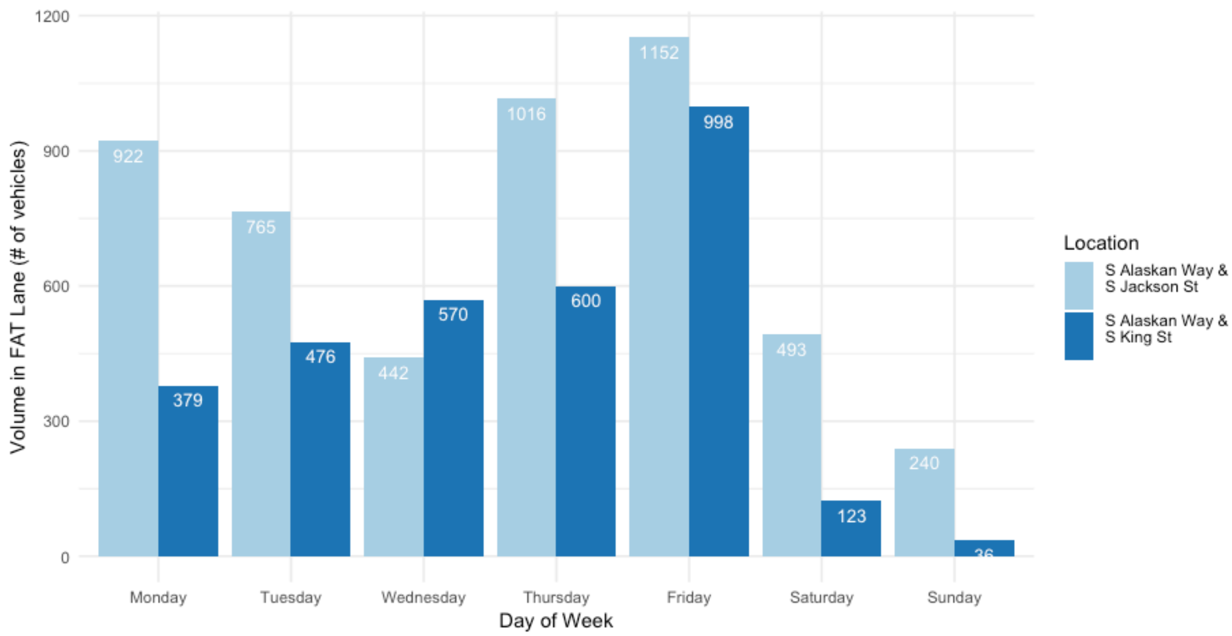
Figure 10: Percentage in the FAT lane by time of day



5. WHAT WAS THE BREAKDOWN OF VEHICLE VOLUME IN THE FAT LANE BY DAY OF THE WEEK?

The distribution of the daily total number of vehicles in the FAT lane over seven days in a week, for two locations, is shown in Figure 11.

Figure 11: Vehicle volumes in the FAT lane by day of the week



A chi-squared statistical test was used to evaluate the statistical significance of this day-of-week analysis. The test performed a goodness-of-fit analysis between the observed data and an expected distribution. The expected distribution (null hypothesis) used for this day-of-week analysis assumed that the volume was not related to the days of the week. So the expected vehicle volume in the FAT lane would equal the total volume divided by 7 on each day. The chi-squared test compared the observed distribution to the expected distribution and determined the statistical significance of their difference. Table 6 shows the results obtained by the chi-squared test.

Table 6: Results of Chi-Squared Tests for Daily Volume in FAT lane

LOCATION	χ^2	P VALUE
S Alaskan Way & Jackson St	941.13	<2.2E-16
S Alaskan Way & King St	1366.3	<2.2E-16

P-values lower than the threshold (0.05) proved that there was a significant relationship between the day of week and the volume in the FAT lane by rejecting the null hypothesis.

Figure 11 shows the following:

The highest volumes were observed on Friday for both locations.

- Location 1: S Alaskan Way and S Jackson St., experienced higher volumes than Location 2: S Alaskan Way and S King St., every day except Wednesday.

6. WHAT PERCENTAGE OF VEHICLES USED THE FAT LANE VERSUS THE GENERAL TRAVEL LANE BY THE DAY OF THE WEEK?

Changes in the percentage of vehicles choosing the FAT lane over the regular lane during seven days of the week were not found to be statistically significant. The chi-squared test showed that the distribution of the percentage in the FAT lane ratio over the days of the week for each location had p values of 0.6082 and 0.07454, respectively, which were higher that the threshold of 0.05.

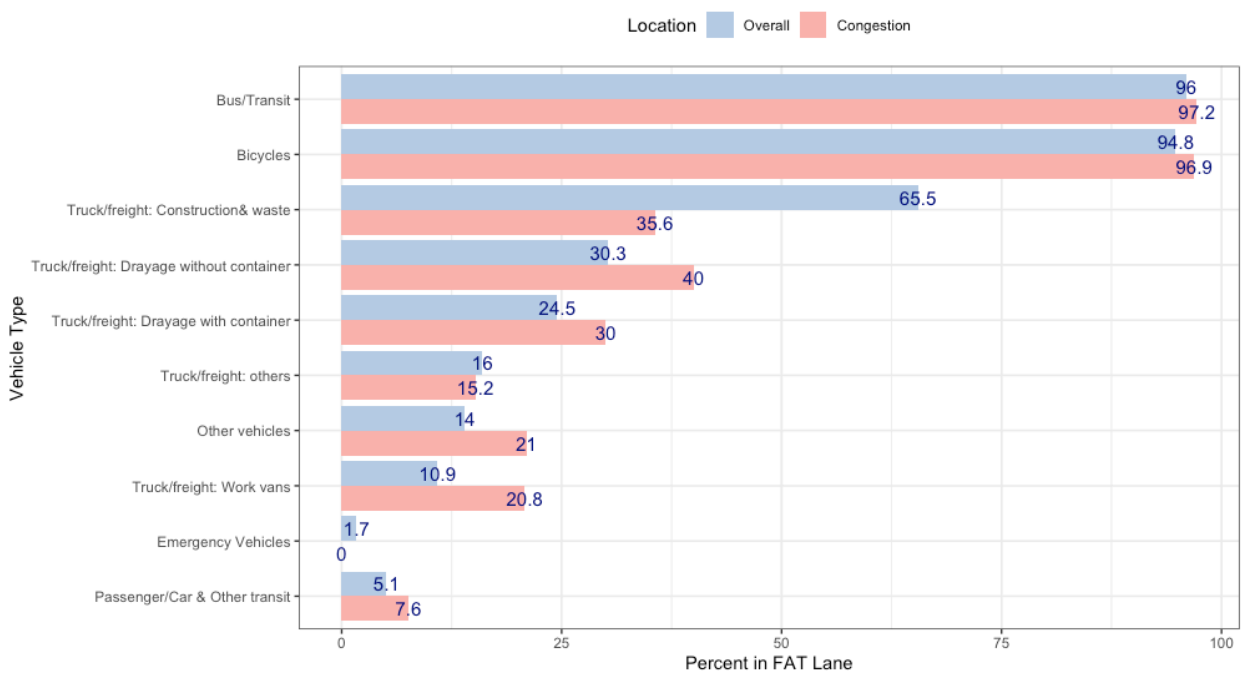
7. HOW DID CONGESTION IMPACT LANE CHOICE (FAT VERSUS GENERAL LANE) FOR DIFFERENT VEHICLE TYPES? HOW DID THE PERCENTAGE IN THE FAT LANE DURING CONGESTION COMPARE TO THE OVERALL AVERAGE IN THE FAT LANE?

Tables 7 and 8 show the vehicle volumes in both lanes for each vehicle type overall and during congested times. The percentage in the FAT lane showed the ratio of vehicles choosing the FAT lane, as seen in figures 12 and 13, by each vehicle type. The overall data included the complete data, 24 hours a day for seven days. The congested data set was the filtered version of the overall data for the congested times determined by the density analysis (see Table 3). The change in percentage in the FAT lane showed how the parameter changed during congestion in comparison to overall.

Table 7: Percent in the FAT lane during congested times and overall at S Alaskan Way and S Jackson St

	S ALASKAN WAY & S JACKSON ST						
	OVERALL			CONGESTION			CHANGE
VEHICLE TYPE	TOTAL VEHICLE VOLUME	VEHICLE VOLUME IN THE FAT LANE	PERCENT IN FAT LANE	TOTAL VEHICLE VOLUME	VEHICLE VOLUME IN THE FAT LANE	PERCENT IN FAT LANE	
Bicycles	727	689	94.8%	160	155	96.9%	2.2%
Bus/Transit	731	702	96.0%	574	558	97.2%	1.3%
Emergency Vehicles	58	1	1.7%	9	0	0.0%	-100.0%
Other vehicles	559	78	14.0%	100	21	21.0%	50.0%
Passenger/Car & Other transit	49428	2514	5.1%	13159	1002	7.6%	49.0%
Truck/freight: Construction& waste	809	530	65.5%	73	26	35.6%	-45.6%
Truck/freight: Drayage with container	159	39	24.5%	20	6	30.0%	22.4%
Truck/freight: Drayage without container	66	20	30.3%	5	2	40.0%	32.0%
Truck/freight: others	1680	269	16.0%	330	50	15.2%	-5.0%
Truck/freight: Work vans	1724	188	10.9%	355	74	20.8%	90.8%
Total	**55941**	**5030**	**9.0%**	**14785**	**1894**	**12.8%**	**42.5%**

Figure 12: Percentage in the FAT lane by vehicle type during congested times and overall at S Alaskan Way and S Jackson St



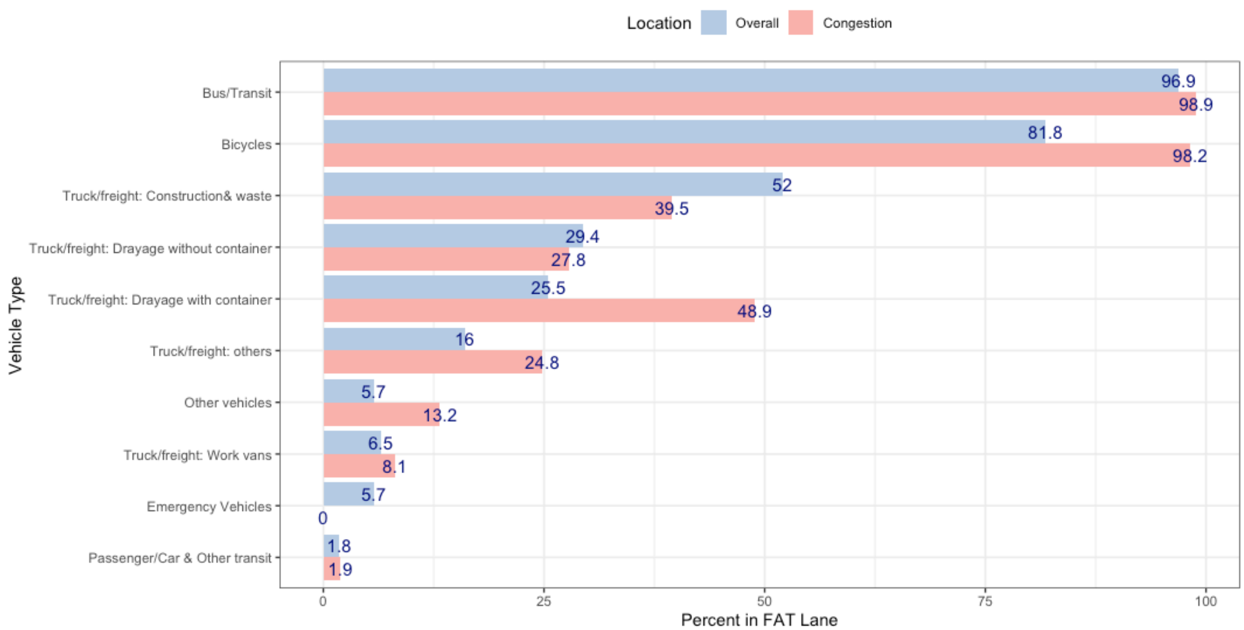
For S Alaskan Way and S Jackson St, the following was found:

- The percentage in the FAT lane increased for the unauthorized vehicle groups comprising passenger cars, other vehicles, and work vans during congested times. The passenger cars started using the FAT lane 49.0 percent more during congestion. The percentage in the FAT lane increased 90.8 percent for work vans.
- The percentage in the FAT lane increased for drayage vehicles with and without container 22.4 percent and 32.0 percent, respectively, during congestion.
- In total, the ratio of the number of vehicles in the FAT lane increased 42.5 percent.

Table 8: Percentage in the FAT lane during congested times and overall at S Alaskan Way and S King St

	S ALASKAN WAY & S KING ST						
	OVERALL			CONGESTION			CHANGE
VEHICLE TYPE	TOTAL VEHICLE VOLUME	VEHICLE VOLUME IN THE FAT LANE	PERCENT IN FAT LANE	TOTAL VEHICLE VOLUME	VEHICLE VOLUME IN THE FAT LANE	PERCENT IN FAT LANE	
Bicycles	439	359	81.8%	112	110	98.2%	20.1%
Bus/Transit	807	782	96.9%	719	711	98.9%	2.1%
Emergency Vehicles	88	5	5.7%	10	0	0.0%	-100.0%
Other vehicles	513	29	5.7%	121	16	13.2%	132.0%
Passenger/Car & Other transit	53196	960	1.8%	16668	311	1.9%	3.7%
Truck/freight: Construction & waste	1288	670	52.0%	223	88	39.5%	-24.1%
Truck/freight: Drayage with container	204	52	25.5%	47	23	48.9%	91.9%
Truck/freight: Drayage without container	68	20	29.4%	18	5	27.8%	-5.5%
Truck/freight: others	1054	169	16.0%	238	59	24.8%	54.9%
Truck/freight: Work vans	2108	136	6.5%	640	52	8.1%	25.0%
Total	**59765**	**3182**	**5.3%**	**18796**	**1375**	**7.3%**	**37.4%**

Figure 13: Percentage in the FAT lane by vehicle type during congested times and overall at S Alaskan Way and S King St



For S Alaskan Way and S King St, the following was found:

- The percentage in the FAT lane increased for drayage vehicles with container 91.9 percent, during congestion. Other vehicles, a group comprising motorcycles, recreational vehicles, and vehicles that were not identified, used the FAT lane 132.0 percent more during congestion.
- In total, the ratio of the number of vehicles in the FAT lane increased 37.4 percent.

RQ2. Were there negative implications of the FAT lane implementation observed in the study area?

Traffic volumes were analyzed to inform decision makers regarding the possible negative consequences of implementing a FAT lane. The volume and percentage in the FAT lane parameters were investigated for freight and transit vehicles specifically and were compared to identify any possible correlation.

1. DID TRANSIT AND FREIGHT VEHICLES USE THE FAT LANE AT DIFFERENT TIMES?

Figures 14 and 15 show the average hourly vehicle volumes in the FAT lane for trucks and buses, respectively, by 24 hours of the day.

- Transit buses almost always used the FAT lane rather than the regular lane, and they reached their highest volumes during peak hours, around 5:00 pm.
- The time windows when vehicle volumes increased in the FAT lane did not coincide for trucks and buses. Trucks reached their volume peak at 10:00 am and 2:00 pm, whereas buses peaked at 5:00 pm.

Figure 14: Average bus and truck volumes by time of day at S Alaskan Way and S Jackson St

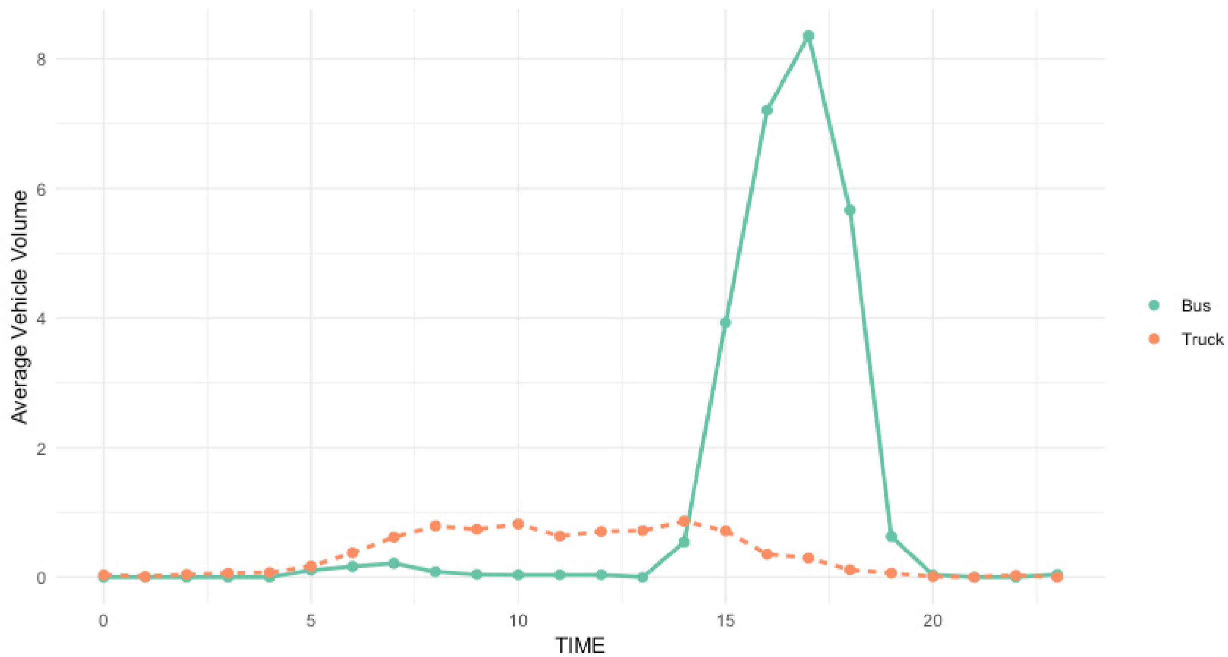
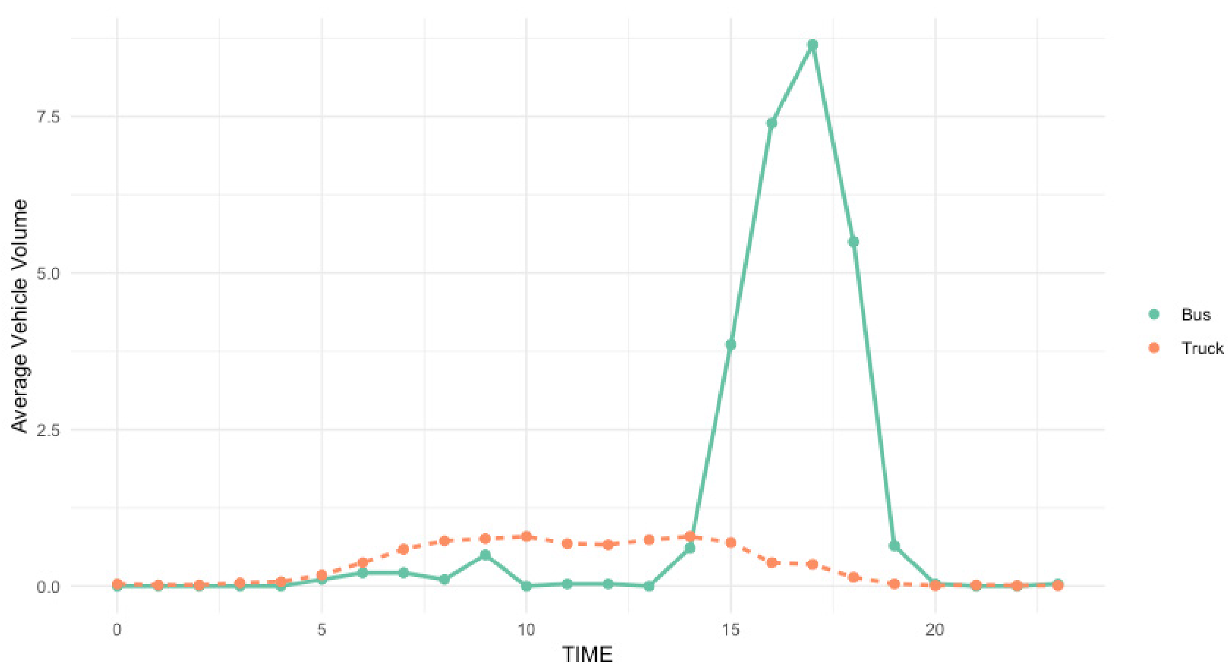


Figure 15: Average bus and truck volumes by time of day at S Alaskan Way and S King St



2. HOW DID THE PERCENTAGE IN THE FAT LANE CHANGE FOR FREIGHT AND TRANSIT VEHICLES BY TIME OF DAY?

Figures 16 and 17 show the fractions of vehicle volumes in the FAT lane for buses and trucks. These are crucial to see when they preferred to use the FAT lane over the regular lane during the day and for scaling purposes, by using the volumes in the regular lane as a baseline.

As the utilization of transit in the FAT lane increased after 1:00 pm, it decreased for freight vehicles. When buses started to use the FAT lane more over the regular lane, some freight vehicles shifted to the regular lane.

Figure 16: Percentage in the FAT lane for buses and trucks by time of day at S Alaskan Way and S Jackson St

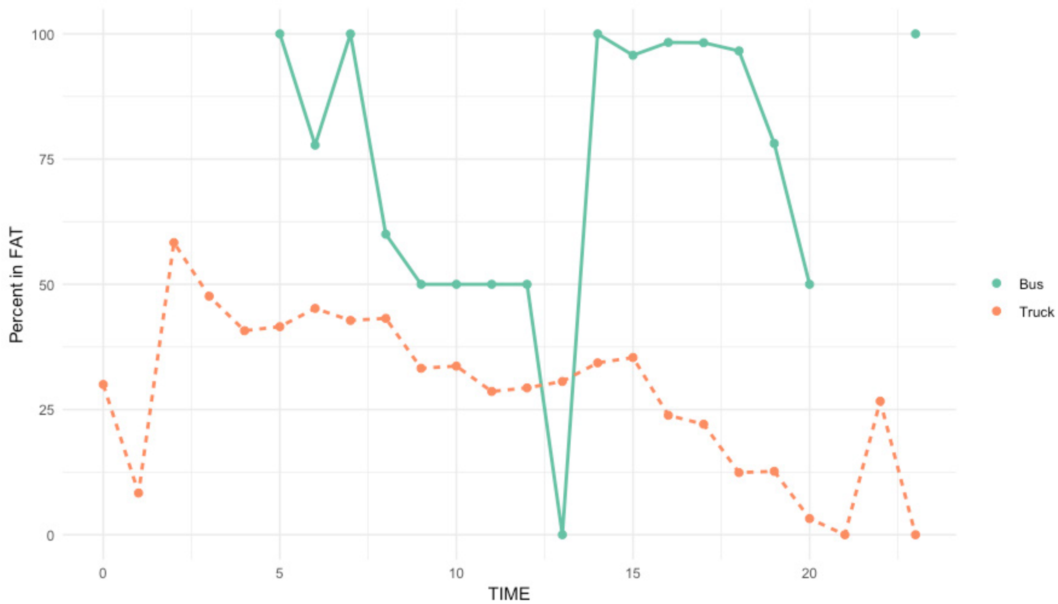
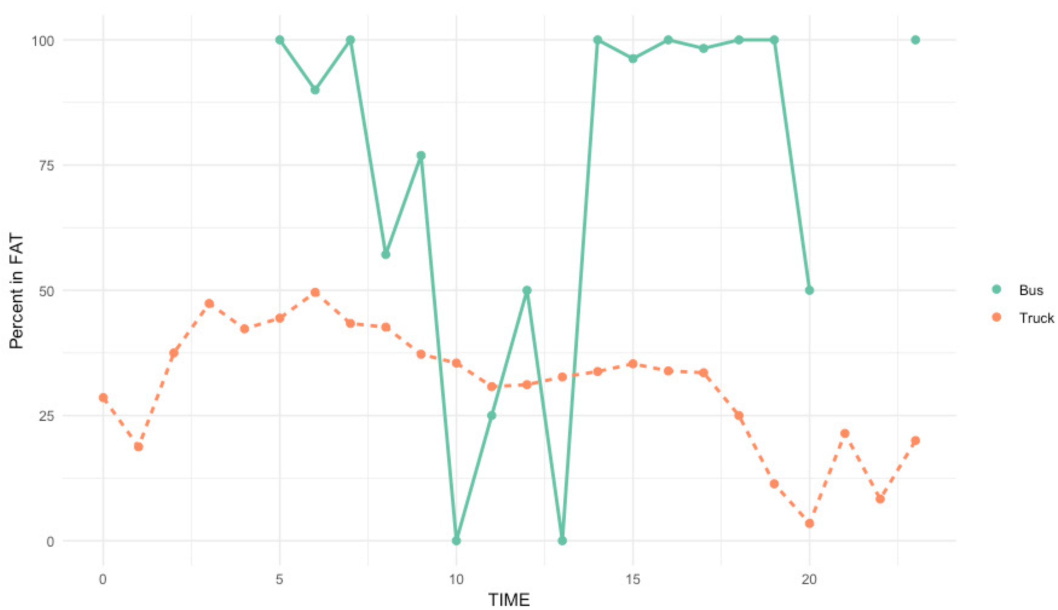


Figure 17: Percentage in the FAT lane for buses and trucks by time of day at S Alaskan Way and S King St



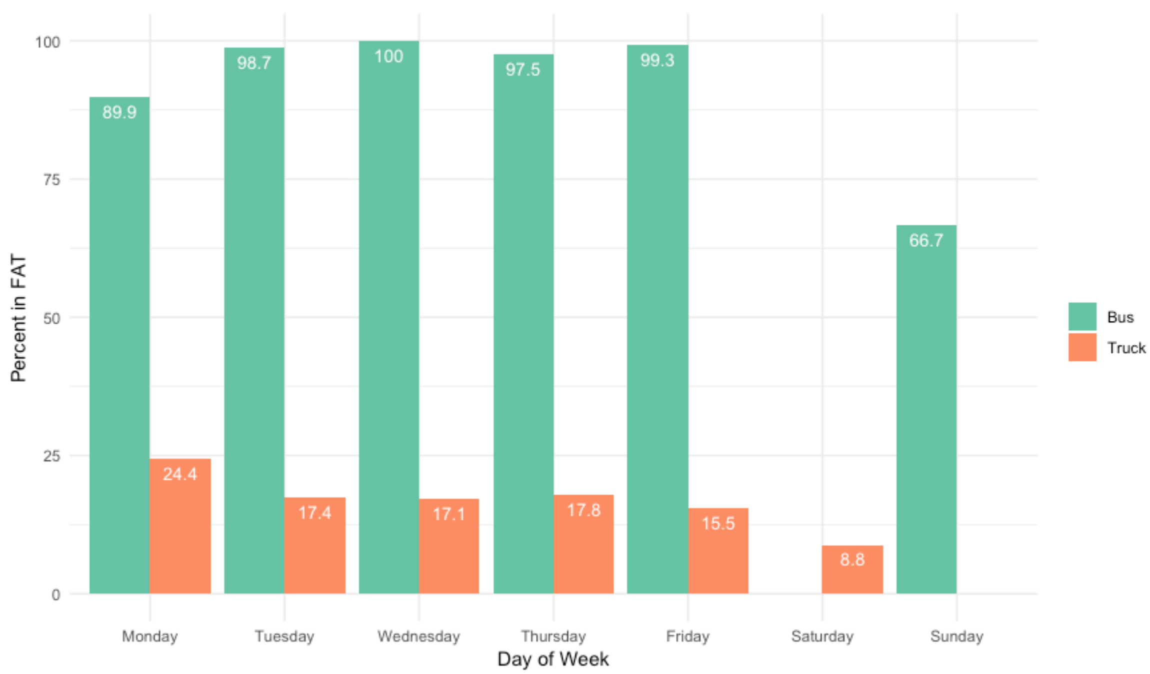
3. HOW DID THE PERCENTAGE IN THE FAT LANE CHANGE FOR FREIGHT AND TRANSIT VEHICLES BY DAY OF WEEK? DID ALLOWING FREIGHT VEHICLES IN THE FAT LANE HAVE A NEGATIVE IMPACT ON THE TRANSIT EXPERIENCE?

Figures 18 and 19 show the weekly trends for transit and freight vehicle choice of FAT lane over the regular travel lane. Again, the percentage in the FAT lane parameter was used to show utilization. The differences in daily percentage in the FAT lane ratios for buses and trucks were tested and found to be statistically significant. The results of the chi-squared test are shown in Table 9. The p-values were lower than the threshold of 0.05.

Table 9: Results of chi-squared tests for difference between percentage in the FAT lane for buses and trucks

LOCATION	χ^2	P VALUE
S Alaskan Way & Jackson St	64.077	6.66E-12
S Alaskan Way & King St	72.716	1.13E-13

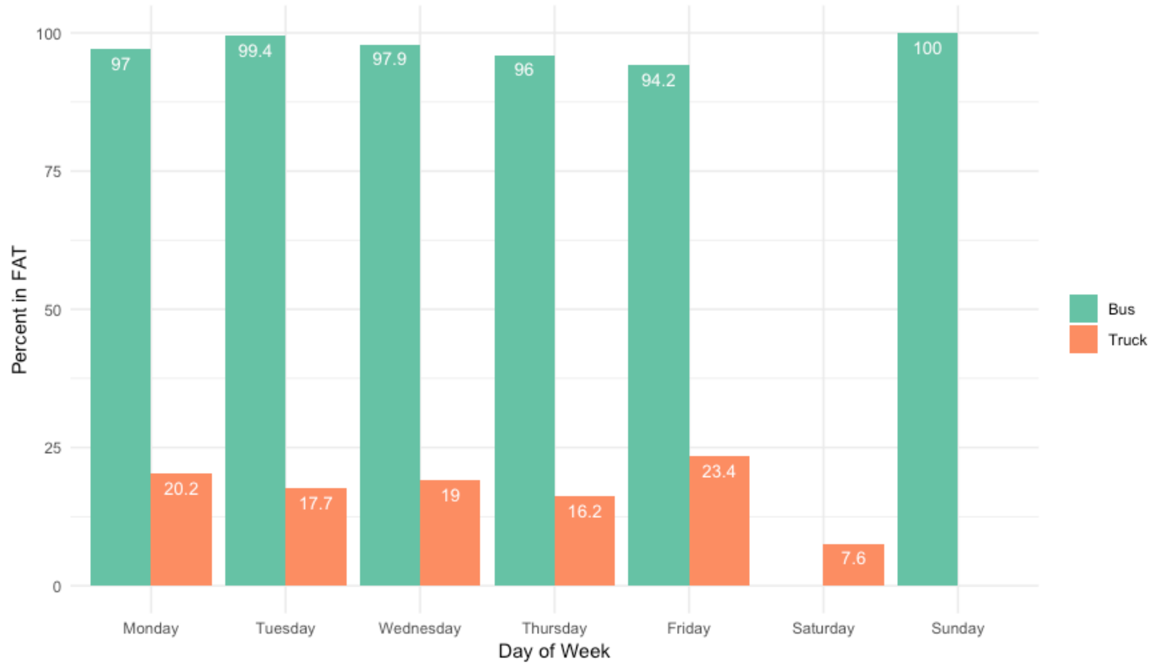
Figure 18: Percent in FAT for Bus and Trucks by Day of Week at S Alaskan Way & S Jackson St



At the intersection of S Alaskan Way and S Jackson St.,

- Monday truck utilization in the FAT lane reached its maximum 24.4 percent, while the bus utilization was lower than usual over the week, 89.9 percent.

Figure 19: Percent in FAT for Bus and Trucks by Day of Week at S Alaskan Way & S King St



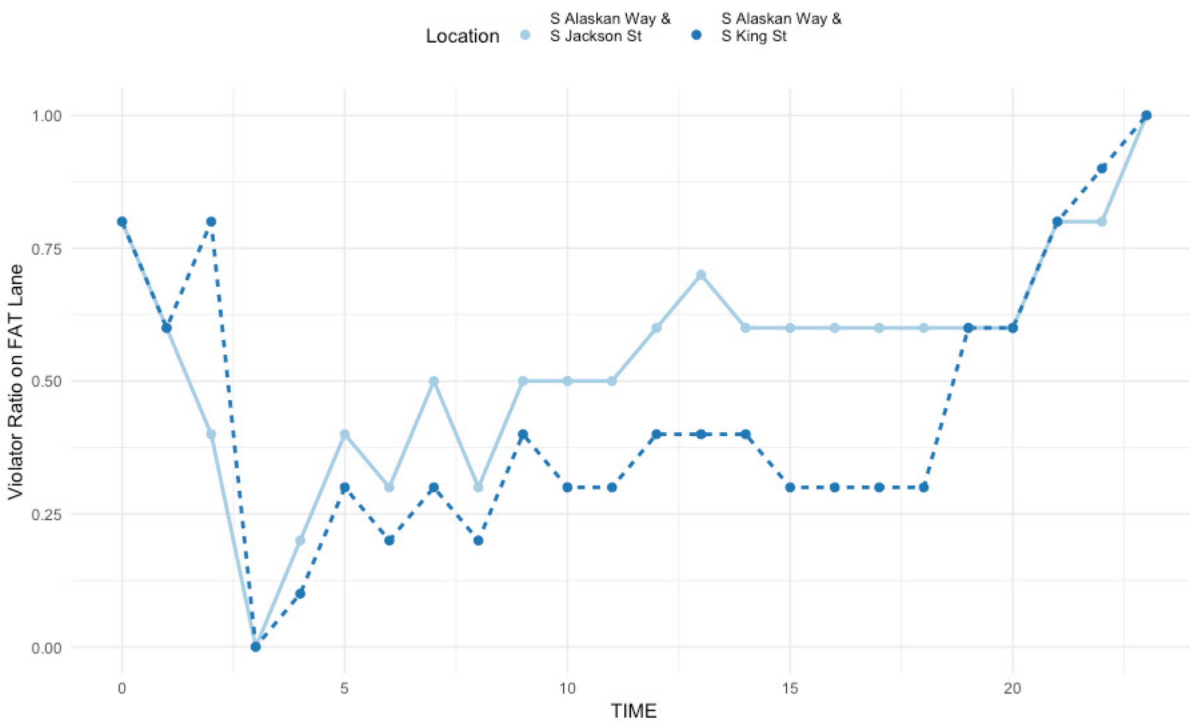
At the intersection of S Alaskan Way and & S King St,

- The percentage in the FAT lane for trucks peaked on Friday, while the percentage in the FAT lane was the lowest for buses on that day.
- No freight activity in the FAT lane was observed on Sunday.
- No transit activity in the FAT lane was observed on Saturday.

4. HOW DID THE VOLUME OF UNAUTHORIZED VEHICLES CHANGE DURING CONGESTION? WERE MORE VIOLATORS SEEN IN THE FAT LANE DURING PERIODS OF CONGESTION THAN IN THE GENERAL LANE?

The violator ratio parameter showed the ratio of unauthorized vehicle volumes over the total volume in the FAT lane (Figure 20).

Figure 20: Violator ratio in the FAT lane



- The violator ratio was observed to be higher than average during afternoon congestion (see Table 3) at both locations.
- At the intersection of S Alaskan Way and S King St, the ratio of unauthorized vehicles in the FAT lane began to increase after 6:00 pm while there was congestion.
- For both locations, high violation rates were observed at night.

The result of this analysis indicated that transit vehicles and bicycles chose the FAT lane over the regular lane. Total vehicle volumes in the FAT lane were the highest on Friday and were found to be statistically significant. The average bus and truck volumes in the FAT lane peaked at different times and followed dissimilar patterns during the day. Some freight vehicles opted out of the FAT lane when bus volumes increased. Use of the FAT lane by unauthorized vehicles was relatively high and was higher when congestion was present.

RQ3. What are desirable characteristics (time of day, days of the week, total flow, flow by vehicle, etc.) to look for in future FAT lane implementations?

Multiple statistical regression models were developed to be used to help decision-makers with implementation and design decisions.

One of the objectives of this study was to identify the factors associated with lane choice. Only the data associated with authorized vehicles were included in this model because that was the only group that was given the choice. So, passenger cars, work vans, and other vehicles were not included in the data to be used in this model. The choice of FAT lane over the regular lane was to be predicted on the basis of multiple variables, such as day of week, location, vehicle type, and density. Density was an alternative dependent variable, meaning it was different for the FAT lane and regular lane choices.

Multinomial logistic regression is used to estimate the categorical dependent variable, in this case lane choice, on the basis of multiple independent variables. Multinomial logistic regression uses maximum likelihood estimation to evaluate the probability of categorical membership.

The multinomial logistic regression model was preferred in this case because it does not assume normality, linearity, or homoscedasticity. The model assumes independence among the dependent variable choices and sample size to be large enough (N=600) [5]. The choice of FAT lane was not related to the choice of regular lane. A multinomial logistic regression model was created by using the GMNL function in the R statistical software package. An iterative procedure was used to obtain maximum likelihood estimates of the regression coefficients (β_i).

The data included a single categorical dependent variable with two categories: FAT lane and regular lane. The independent predictor variables were listed as day of week, location, time of day, and vehicle type. These variables were used alternatively to estimate the best working model with the highest McFadden R^2 value and low p values for the coefficients. The McFadden R^2 ranges between 0 and 1 and accounts for improvement from the null model (without any predictors) to the fitted model. McFadden R^2 values between 0.2 and 0.4 represent excellent fit.

The variables included in the model were determined by generating multiple mlogit fit models. The final model included only the statistically significant variables. For example, only the morning (5:00 am to 10:00 am) and afternoon (1:00 pm to 5:00 pm) time of day features were found to be statistically significant (low p values) and were included in the final model. The same procedure was applied for the categorical day of week variables.

The utility functions for a logit model can be described as follows:

$$u_{choice} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots$$

The utility functions are used for calculating the choice probability. The choice variables in this model are the FAT lane and regular lane.

$$Probability_{FAT\ lane} = \frac{e^{u_{FAT\ lane}}}{e^{u_{FAT\ lane}} + e^{u_{Regular\ lane}}}$$

The results in Table 10 show the logistic coefficient for each predictor variable for each choice category of the outcome variable. The logistic coefficient (β_i) is the expected amount of change in the utility function for each one unit change in the variable. The choice probability shown above increases as the utility function increases. So, the closer a coefficient is to zero, the less influence the predictor has in predicting the choice.

The t-test for each coefficient was used to determine whether the coefficient was significantly different from zero. The p-value showed the significance of each variable contributing to the prediction of lane choice. Only the interpretation of significant variables was relevant.

Table 10: Multinomial logistic regression for lane choice model results

REFERENCE	CATEGORIES	VARIABLES	COEFFICIENT	STANDARD ERROR	T-VALUE	P-VALUE
Regular lane	Intercept		-1.950	0.125	-15.634	< 2.2e-16 (***)
Regular lane	Time of day	Morning	-0.302	0.076	-3.969	0.000 (***)
Regular lane		Afternoon	-0.225	0.077	-2.926	0.00343 (**)
Regular lane	Day of Week	Wed.-Thurs.-FrI.	-0.220	0.066	-3.350	0.000 (***)
Regular lane		Sat.-Sun.	-0.200	0.120	-1.659	0.0971 (.)
Regular lane	Location	Jackson St (base)				
Regular lane		King St	0.403	0.067	6.058	0.00 (***)
Regular lane	Vehicle Type	Bicycles (base)				
Regular lane		Bus/Transit	-1.241	0.174	-7.123	0.00 (***)
Regular lane		Emergency Vehicles	5.163	0.431	11.982	< 2.2e-16 (***)
Regular lane		Truck/freight: Construction& waste	1.802	0.109	16.604	< 2.2e-16 (***)
Regular lane		Truck/freight: Drayage with container	3.194	0.157	20.295	< 2.2e-16 (***)
Regular lane		Truck/freight: Drayage without container	2.980	0.215	13.866	< 2.2e-16 (***)
Regular lane		Truck/freight: others	3.852	0.113	34.220	< 2.2e-16 (***)
FAT lane	Density		-0.201	0.213	-0.944	0.345
Regular lane			-0.221	0.120	-1.839	0.0659 (.)
McFadden pseudo R2						0.377
Log Likelihood						-3525.6
AIC (fitted model)						7079.134
AIC (null)						11315.86

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The probability of choosing the FAT lane over the regular lane for all vehicle types was found to be higher:

- during the morning and afternoon time periods, since they had negative coefficients for the regular lane alternative, and
- on Wednesdays, Thursdays, and Fridays in comparison to the other days of the week.

Buses were more likely to choose the FAT lane over the regular lane than the other vehicle types (as shown by the negative coefficient for the regular lane alternative). Freight vehicles comprising drayage with container and drayage without container were less likely to use the FAT lane than construction and waste vehicles and more likely than emergency vehicles.

The probability of choosing the FAT lane was higher at the intersection of S Alaskan Way and S Jackson St, which was upstream (north) of the FAT lane.

The AIC parameter of the fitted model was lower than the null model (without any predictors), which indicates that the model was more parsimonious relative to the null model.

RQ4. What are some additional considerations for future FAT lane case studies?

This section includes further qualitative observations and discussion of behaviors such as lane changes and right turns. The FAT lane spanned over two blocks and was observed in this study at two adjacent intersections. During the data collection process, we gathered certain observations that are critical to consider for further implementations.

Vehicles were changing lanes in both directions frequently.

- Vehicles traveling in the regular lane often decided to turn right at the last minute and move into the right hand lane. In some instances they did not enter the FAT lane and turned right from the regular lane, even though right turns were permitted from the FAT lane.
- Vehicles that were unauthorized in the FAT lane, moved to the regular travel lane after they saw the signage. This often created queues in the FAT lane, as following vehicles waited for right of way.
- Transit buses used the FAT lane regularly and showed high utilization rates of the FAT lane. SDOT stated that bus drivers were given information beforehand about the FAT lane application, whereas freight vehicle drivers were not. Most vehicle types, other than transit buses and bicycles, showed irregular activity that may have resulted from insufficient signage and information.

CONCLUSION

Analysis of traffic volumes showed that transit buses used the FAT lane at the two locations 96.0 percent and 96.9 percent of the time, respectively, and authorizing freight vehicles to use the lane did not impact that lane choice.

The percentage in the FAT lane ratio was 96.0 percent 96.9 percent for transit buses at the two locations and 81.8 percent and 94.8 percent for bicycles, which preferred to use the FAT lane more than other vehicles. The transit bus volume peak at 5:00 pm, whereas truck volumes peaked between 10:00 am and 2:00 pm and showed a decreasing trend around 5:00 pm, afternoon rush.

Some trucks used the FAT lane, but their utilization decreased with increasing numbers of buses in the FAT lane. Truck percentage in the two FAT lane locations peaked at 3:00 pm at 35.4 percent and, 35.3 percent, but decreased as bus volumes increased in the FAT lane around 5:00 pm.

The percentage of all vehicles in the FAT lane increased by 42.5 percent and 37.4 percent for the two locations during congestion. Instead of higher rates of trucks, more unauthorized vehicles, such as work vans and other vehicles, increasingly used the FAT lane during congested periods. This shows that congestion led to higher violation rates in the FAT lane.

The results of the multinomial logistic regression model showed that the time of day, location, day of week, and vehicle type influenced lane choice. For all vehicle types, the probability of choosing the FAT lane was higher during the morning and afternoon hours, and on Wednesdays, Thursdays, and Fridays.

For future projects, it is recommended that clearer signage and information be provided for drivers.

Freight companies may also be notified beforehand so that the drivers will know about the location and functionality of the implementation. Qualitative observations showed that many drivers were confused by the FAT lane implementation in the area. Signage located before the area can be used to inform drivers about the specifications of the FAT lane.

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