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Evaluating Traffic Impacts of Permitting Trucks in Transit-Only Lanes

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Abstract

With ongoing population growth and rapid development in cities, the demand for goods and services has seen a drastic increase. Consequently, transportation planners are searching for new ways to better manage the flow of traffic on existing facilities, and more efficiently utilize available and unused capacity. In this research, a lane management strategy that allows freight vehicles to use bus-only lanes is empirically evaluated in an urban setting. This paper presents an analysis of data that was collected to evaluate the operational impacts of the implementation of a freight and transit (FAT) lane, and to guide the development of future FAT lane projects by learning from the case study in Seattle, U.S. The video data was converted to vehicle counts, which were analyzed to understand the traffic impacts and used to construct a discrete choice model. The analysis shows that transit buses used the FAT lane 96% of the time, and authorizing trucks to use the lane did not affect that lane choice. Trucks used the FAT lane, but their utilization decreased with increasing numbers of buses in the FAT lane. Instead of higher rates of trucks, unauthorized vehicles, such as passenger cars and work vans, increasingly used the FAT lane during congestion. As a result of their differing schedule patterns, trucks and buses used the FAT lane at complementary times and trucks showed relatively low volumes in the FAT lane. Overall, the results are promising for a lane management strategy that may improve freight system performance without reducing transit service quality.

Between 2010 and 2019, the total number of vehicle miles traveled in the U.S. on all roads and streets increased by 9.5% (*1*). Transportation planners have been working to tackle the congestion and limited roadway capacity problems caused by this growth. Accommodating additional traffic flow is challenging in urban areas because of increased construction costs and limited expansion capacity, and many regions prefer to use management strategies that can find additional capacity on the existing infrastructure. Thus, planners are searching for new ways to find capacity in the road network (*2*).

Managed lanes have been used for over 50 years as a strategy to reduce congestion (*3*). As urban streets face higher demand—and, as a result, higher congestion—cities around the world are pursuing strategies to maximize their productivity and livability for their many users. Often, the development of managed lanes has come from the realization that high demand on existing facilities necessitates the efficient management of those facilities (*4*). Bus-only lanes have caught the attention of planners and policymakers as a less expensive, flexible, and practical solution to provide high-quality transit service in areas with high congestion levels (*5*).

This research explores the behavior of roadway users when a bus-only lane is opened to truck traffic to examine whether unused capacity in a bus-only lane can be utilized by freight vehicles without negatively affecting bus service. The idea is that reallocation of existing resources—adding trucks to bus-only lanes, to further utilize road capacity—may improve traffic flow on both managed and general-purpose lanes. The purpose of this study is to evaluate the efficacy of the freight and transit (FAT) lane practice, and to guide the development of future projects based on data and parameters that are extracted from the pilot test in Seattle. This paper presents a data collection and analysis to evaluate the case study area, as well as recommendations for future implementations.

The City of Seattle Department of Transportation (SDOT) is interested in the use of managed lanes to

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provide additional capacity for roadway users. As a result, they tested a strategy of allowing trucks to use a bus-only lane in one of Seattle's industrial areas. SDOT temporarily installed two blocks of FAT lane on Alaskan Way to improve truck access to commercial and industrial areas in the city. Trucks (not including work vans) were authorized to use the FAT lane, a former bus-only lane, for 24 h a day alongside bicycles. Freight vehicles allowed in the FAT lane included heavy goods vehicles (HGVs), garbage and construction trucks, and single-unit trucks. This study uses street camera recordings provided by SDOT as the primary data source. The given data covers 7 days—a full week during the implementation period. The study area is shown in Figure 1.

The remainder of the paper is organized as follows. First, relevant literature on managed lane implementations is reviewed. Following this, the study area and methodology used in this study are described. Then, the compliance level by freight vehicles is analyzed—for example, what percent of trucks use the FAT lane, and does that depend on FAT lane use by other vehicles or on other variables such as time of day and day of the week? Then, truck and bus volumes in the FAT lane and general-purpose lane are compared to investigate any negative operational implications of the implementation. Truck and bus volumes, along with their compliance levels in the FAT lane, are compared to identify any existing relationships. The analysis includes the changes in the behavior of trucks and unauthorized vehicles when there is congestion. Finally, a discrete choice model is employed to identify factors such as time of day, and vehicle type and density associated with lane choice.

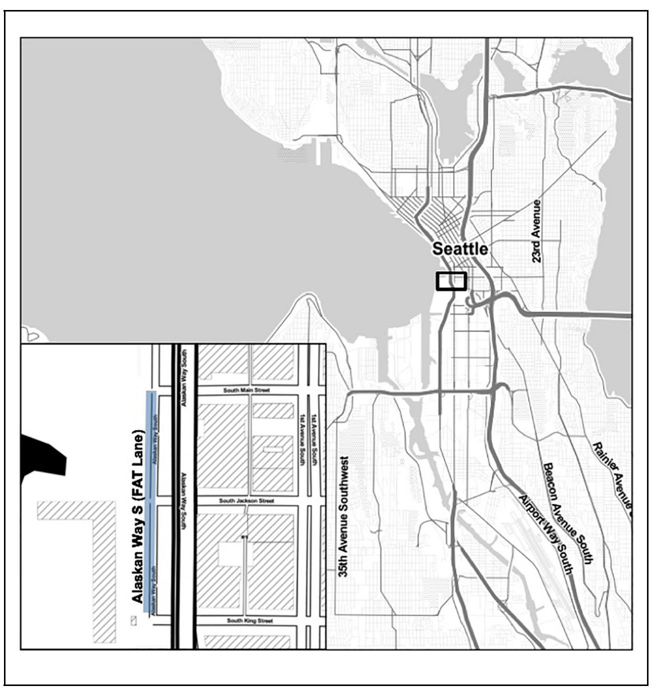

Figure 1. Study area in Seattle, U.S.

Literature Review

The definition of a managed lane varies between agencies because managing techniques differ to better match regional goals (*6*). The Federal Highway Administration (FHWA) defines managed lanes as "a set of lanes where operational strategies are proactively implemented and managed in response to changing conditions" (*2*). The FAT lane was introduced to better adjust to the closure of a major thoroughfare and improve FAT access on the already congested road network in Seattle. The implementation of the FAT lane is therefore accounted as a managed lane strategy. Texas Department of Transportation mentions that the definition of managed lanes reflects its complex and flexible nature that allows for adjustments to better meet the needs of the community (*6*). Types of managed lane strategies include truck lane restrictions, bus-only lanes and exclusive truck facilities, serving a specific type of vehicle. FHWA lists 12 examples of managed lane applications, none of which serve both transit and freight vehicles simultaneously; this suggests such practices are not as common in the U.S.

Restricted multi-use lanes are defined as traffic control and lane management strategies that allocate lane usage to a restricted set of vehicle types using time windows or at all times (*7*). To gain a broad understanding, examples of restricted multi-use lanes that permit freight vehicles to utilize bus lanes and allow for shared use in the lane are analyzed. Although the use of bus-only lanes by goods vehicles has been proposed repeatedly, there have been few examples of FAT lanes implemented in urban areas (*8*, *9*).

The city of Newcastle-upon-Tyne, U.K., introduced a bus and goods vehicle lane in 1992, as a method to facilitate goods and people movement in congested urban areas. The monitoring process at the time revealed that a small share of freight vehicles used the lane, and the queues near bus stops resulted in delays for freight vehicles (*8*, *9*). However, this initiative subsequently led to the implementation of "no-car lanes" in the area, that can be used by buses, goods vehicles, taxis, motorcycles, and bicycles, excluding cars, between 7:00 a.m. and 7:00 p.m., and are still in operation (*10*). Mulley studied the impact of no-car lanes and bus-only lanes on different traffic users using simulation tools and data sources including feedback from drivers and traffic flow counts. Simulation analysis results showed that when bus-only and no-car lanes are in operation, the average travel time for HGVs increases by 8.7% and 0.3%, respectively, when compared with no priority in the lane. The analysis of manual classified counts showed that the percent of unauthorized use by cars in the lane was 2.41% in no-car lanes, and 0.71% in bus-only lanes. The higher percent of violators in the no-car lane suggested that enforcement is more difficult when the permitted traffic is less homogeneous in a particular road space. Also, cars were more likely to use no car-lanes in the evening peak period, particularly in the final hour (6:00–7:00 p.m.) that enforcement applies (*11*).

Since restricted multi-use lane strategies can reduce travel delays, they are also used as incentives for the implementation of other strategies. For example, clean freight vehicles are allowed to use the bus lane to promote the use of environmentally friendly trucks in Gothenburg, Sweden, and freight vehicles that use the consolidation center are allowed in the bus lane to foster the use of the consolidation center in Bristol, U.K. (*7*). Similarly, a 6 month pilot test on urban freight deliveries in Norwich, U.K., was implemented to allow low emission, HGVs in the bus-cycle lane. The purpose of this pilot was to both encourage the use of clean transportation vehicles and improve freight mobility in the city. The lane width of existing bus lanes was a barrier to permit freight vehicles in the lane, thus only low-emission vehicles that were traveling to and from the local logistics facility, Norwich Freight Consolidation Center (NFCC), could use the lane. The vehicle drivers associated with NFCC were trained on how and when to drive in the bus lane. Researchers found that the travel time for freight vehicles during peak hours can be reduced by 2–4 min per trip, which were 25 min on average, by measuring total trips per day and average vehicle speed (*12*).

Other implementations suggested that the bus-only lane can be used by other vehicles whenever buses were not using the lane. The concept of intermittent bus lanes was proposed by Viegas et al. and was demonstrated in Lisbon as a 6 month pilot project (*13*). Using data captured by loop detectors on every lane, the study found a 5%–20% increase in bus average speed and no significant impact on the general traffic. There are other studies that concentrate on the evaluation of intermittent bus lanes, such as Currie and Lai, and Zyryanov and Mironchuk, but the permission to use the bus lane is not exclusive to freight vehicles (*14*, *15*). Another type of multi-use lane, implemented as "Lincoln" delivery bays in Paris, allows trucks to temporarily park in bus lanes to unload in specific locations, but not for travel (*7*, *16*).

Relevant to the intermittent bus lane concept, the dynamic control of individual goods vehicles in urban centers is tested by using a simulation model of Winchester city, U.K., within the scope of the SmartFreight project. When HGVs were allowed to use the shared lane (approximately 40 per hour), the travel times increased over all vehicles by 8%, with negligible travel time reduction for HGVs. The overall benefits for different vehicle groups were found to be statistically insignificant, possibly because the lane covered a short section of road (160 m) (*8*).

The majority of the studies reported in the literature use simulation technologies to investigate the outcomes of managed lanes. Theoretical research does not capture all practical situations, therefore a real world application is necessary to act as a prototype (*13*). Real-life applications play a key role in assessing the impacts of potential initiatives and provide an opportunity for all stakeholders to give guided decisions about whether to move ahead with a full implementation, modify, or stop. They could also demonstrate to the private sector that the public sector is proceeding carefully with the implementation of new ideas and applying only those that are successful (*7*). Prior studies, such as Viegas et al. and Currie and Lai, have employed pilot tests, and investigated the intermittent use of bus-only lanes that allow all vehicles in the bus-only lane when it is not used (*13*, *14*). The main objective of the pilot test in Norwich, U.K., was to encourage environmentally friendly vehicles; therefore only clean vehicles were permitted in the bus lane. The pilot presented in the current study adds to the existing research by assessing a shared-use lane without time windows and vehicle restrictions, and employs empirical data to evaluate the outcomes.

Study Area

This study has been conducted in the city of Seattle, WA, shown in Figure 1.

Seattle has been the fastest growing major city in the U.S. for almost 10 years (*17*). With this ongoing population growth, the demand for goods and services in Seattle has also been increasing. This increase is reflected in the city of Seattle's goals and identified strategies in the Freight Master Plan (FMP). One of these strategies includes exploring and testing the use of truck-only or shared-use lanes (*18*). This strategy was implemented by opening the FAT lane on the closing of the Alaskan Way Viaduct at S Alaskan Way/S Jackson St, and S Alaskan Way/S King St.

The Alaskan Way Viaduct, an elevated section of State Route 99, was built in the 1950s. According to the Washington State Department of Transportation, replacing the viaduct was critical to public safety because of its age and vulnerability to earthquakes (*19*). The viaduct was replaced with a 2 mi-long tunnel beneath downtown Seattle, and was closed on January 11, 2019. The closure of this major thoroughfare significantly reduced capacity on the already congested road network in greater downtown Seattle. The City of Seattle Department of Transportation temporarily implemented two blocks of

Figure 2. Location of the freight and transit (FAT) lane and street cameras.

FAT lane on Alaskan Way to prioritize buses and trucks in congested locations and reduce the impact of constriction points (*20*).

The FAT lane was in the curb lane only, on the southbound Alaskan Way at street level. The surface street on Alaskan Way consists of four lanes of traffic along the specified section, including two lanes in each direction. The FAT lane is installed in one lane in the southbound direction. 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. Plus, it provided access to the Seattle Ferry Terminal (Colman Dock), where passenger ferries and water taxis travel to nearby islands. The FAT lane was in operation 24 h a day, and there were no bus stops on the two-block strip. SDOT installed two video cameras at the two intersections to observe operations after the implementation. Figure 2 shows the two-block strip where the FAT lane was installed and the locations of the street cameras: Location 1: S Alaskan Way/S Jackson St, and Location 2: S Alaskan Way/S King St.

Methodology

Data Collection

The data used for this study was provided in video format by SDOT. The street camera recordings were taken 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/S Jackson St, and S Alaskan Way/S King St (see Figure 2). The recordings were dated January 24–30, 2019 (24 h video recordings), covering a full week.

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 time needed to complete the manual data reduction was 37.3 min per 1 h video on average. The vehicle counting was performed for two lanes (the FAT lane and the general-purpose lane) in the southbound direction at each location.

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. 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 min interval, was recorded as a single number on the data collection spreadsheet.

All right turners were permitted to use the FAT lane regardless of their vehicle type. The number of vehicles turning right in the FAT lane was counted separately so that they could be distinguished from violators and be excluded from the data to be used in the analysis. In this context, violators are unauthorized vehicles in the FAT lane that do not make a right turn.

Nine vehicle categories were developed so that separate freight, transit, and other road users could be analyzed (see Table 1). Because the FAT lane supported the services of the port, drayage vehicles (with or without container) were given their own category separate from other trucks. Table 1 shows each vehicle category's authorization to use the FAT lane.

Analytical Methods

Density Analysis. To examine how congestion might affect lane choice, the time periods of congestion were identified by using density analysis. Traffic flow theory defines density as the number of vehicles per unit length, a spatial measurement (*21*). As density increases, the space-mean speed monotonically decreases, and higher values for the density indicate almost always a worsening of the traffic conditions, such as congested traffic (*11*). For this study, density is defined as the number of vehicles per unit link length and calculated as follows:

$$k_i = \frac{n_{FATlane} + n_{GPlane}}{l} \tag{1}$$

where:

$n_{FATlane}$ is the number of vehicles in the FAT lane;
n_{GPlane} is the number of vehicles in the general-purpose lane;

Table 1. Types of Vehicles across Nine Vehicle Categories

Vehicle category	Definition	Authorization on the freight and transit (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	Bicycles	Authorized	
Truck/freight: drayage	Trucks consisting of 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). They are used for drayage with or without a container.	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 (right turns permitted)	

(continued)

Table 1. (continued)

Vehicle category	Definition	Authorization on the freight and transit (FAT) lane	Visual
Passenger car and other transit	Sedans, coupes, SUVs, mini-vans, and 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 10 people. School, public, private, or commercial passenger-carrying buses and passenger vans, excluding public transit.	Not authorized (right turns permitted)	
Emergency vehicles	Vehicles used by emergency response teams (e.g., fire trucks, ambulances, and police cars).	Authorized	
Other vehicles	All others—all two- or three-wheeled motorized vehicles, vehicles designed for recreation or camping, and vehicles that fail to be identified.	Not authorized (right turns permitted)	

l is the distance between the start of the intersection and the farthest point visible in the video data; and
k_i is the density measure at time slot i.

Screenshot images were taken every 15 min from the video recordings. The numbers of vehicles in the FAT and general-purpose lanes were counted. To normalize between two locations, the vehicle counts were divided by the link length to obtain density measures. These were averaged over each hour, since instantaneous measures could not be used to define time intervals and then smoothed using hourly moving averages. The smoothed density values were sorted to find the hours that had the highest three values—the peak hours. The congested times are determined to be the union of peak hours in the FAT and general-purpose lane. The density analysis is conducted separately for two locations. To obtain the vehicle count data during congestion to be used in further analysis, the complete vehicle count data, including 24 h a day for 7 days, was filtered by the determined congested time intervals.

Percent in FAT. This study uses the "Percent in FAT" parameter, introduced to assess the utilization of the FAT lane, which is the ratio of vehicles in the FAT lane over the total number of vehicles, given by Equation 2 below.

$$Percent\ in\ FAT = \frac{Vehicle\ count\ in\ FATlane}{Sum\ of\ vehicle\ count\ in\ FAT\ and\ regular\ lane} * 100 \quad (2)$$

This value is related to the utilization and the tendency of vehicles to prefer the FAT lane over the general-purpose lane. The metric also serves the purpose of scaling and allows logical comparisons between different vehicle groups.

Violator Ratio. Violator ratio is the proportion of the number of unauthorized vehicles over the total number of vehicles in the FAT lane, given by Equation 3 below. As mentioned earlier, right turners of all vehicle types are permitted in the FAT lane, therefore they are not included in the vehicle counts.

$$Violator\ ratio = \frac{Number\ of\ unauthorized\ vehicles\ in\ FAT\ lane}{Number\ of\ all\ vehicles\ in\ FAT\ lane} * 100 \quad (3)$$

This value is used to measure contravention and is related to the tendency of unauthorized vehicle groups, passenger cars, work vans, and other vehicles to use the FAT lane without authorization.

Discrete Choice Analysis. Discrete choice analysis is applied using a logit model, to study the probability of individuals choosing a particular alternative among various discrete alternatives based on the utility that they derive from their choice decision. The coefficients of the logit model are estimated by a maximum likelihood function.

The logit model is useful to predict the impact of changes in the explanatory variables, such as the influence of vehicle type or congestion, measured as the density variable, on lane choice. The set of feasible lane alternatives available for an individual driver n is assumed to consist of $C = \{FATlane, general\ purpose\ lane\}$. An individual driver n is characterized by specific variables—vehicle type, time of day, and day of week—and chooses a lane alternative $i \in C$ considering the alternative specific variable: density. The data shows the observed lane choices of individuals. For example, if an individual is observed and counted in the FAT lane, they chose the FAT lane rather than the general-purpose lane. It is assumed that drivers are free to choose any lane desired. The data set is organized to have as many rows as there are choices for each choice situation and is in a long shape form. There are two lane choices (FAT lane or general-purpose lane) and most of the variables are individual specific.

Random utility theory proposes that subjects choose among alternatives according to a utility function with two main components: a systematic (observable) component and a random error term (non-observable). The utility function of driver n for an alternative i in a choice set C is:

$$U_{ni} = \beta^T x_{ni} + \epsilon_{ni} = V_{ni} + \epsilon_{ni}; \quad (4)$$

where:
x_{ni} is a vector of attributes;
β is a vector of marginal utilities of attribute levels;
V_{ni} is a function of observable covariates; and
ϵ_{ni} is the error term.
Driver n will choose the alternative, i, which provides them the highest utility compared with other alternatives. The model assumes that the error terms are independent, and identically distributed (*22*). The general expression of the probability of an individual driver n choosing alternative i (P_{ni}), among two alternatives, is then:

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_{j \in C} e^{V_{ni}}} \quad (5)$$

Multiple logit models were developed to determine significant attributes that are likely to influence lane choice, using the MLOGIT package in the R statistical programming software. An iterative procedure was used to obtain maximum likelihood estimates of the regression coefficients (β_i). The explanatory variables were used alternatively to estimate the best working model in terms of McFadden's R2 value, Akaike information criterion (AIC), improvement in the likelihood functions, and significance of coefficient estimates.

This study characterizes the probability of choosing the FAT lane over the general-purpose lane for authorized vehicles. Thus, only the data associated with authorized vehicles were included in this model, because that was the only group that was given the choice. Because of this, passenger cars, work vans, and other vehicles were not included in the data to be used in this model.

Results

Compliance Level by Vehicle Type

The volumes of vehicles traveling through intersections at the two count locations are compared to identify the vehicle volumes in each lane. After understanding what comprises the vehicle volume in both lanes, the percent in FAT parameter is used to indicate their utilization of the FAT lane. The data from two separate locations are treated separately throughout the analysis to investigate whether the results change with location.

The highest share of vehicles in the FAT lane at both locations comprised passenger cars, constituting 50% and 30% 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% and 21% of the vehicle volumes in each FAT lane, respectively.

Figure 3 shows the percent in the FAT lane, calculated for each vehicle type. The percent in the FAT lane ratio was 96.0% and 96.9% for transit buses at the two locations, and 81.8% and 94.8% for bicycles, which preferred to use the FAT lane more than other vehicles. Construction and waste vehicles used the FAT lane much more frequently than other heavy goods freight vehicles. They chose the FAT lane over the general-purpose lane 52% and 65.5% of the time for each

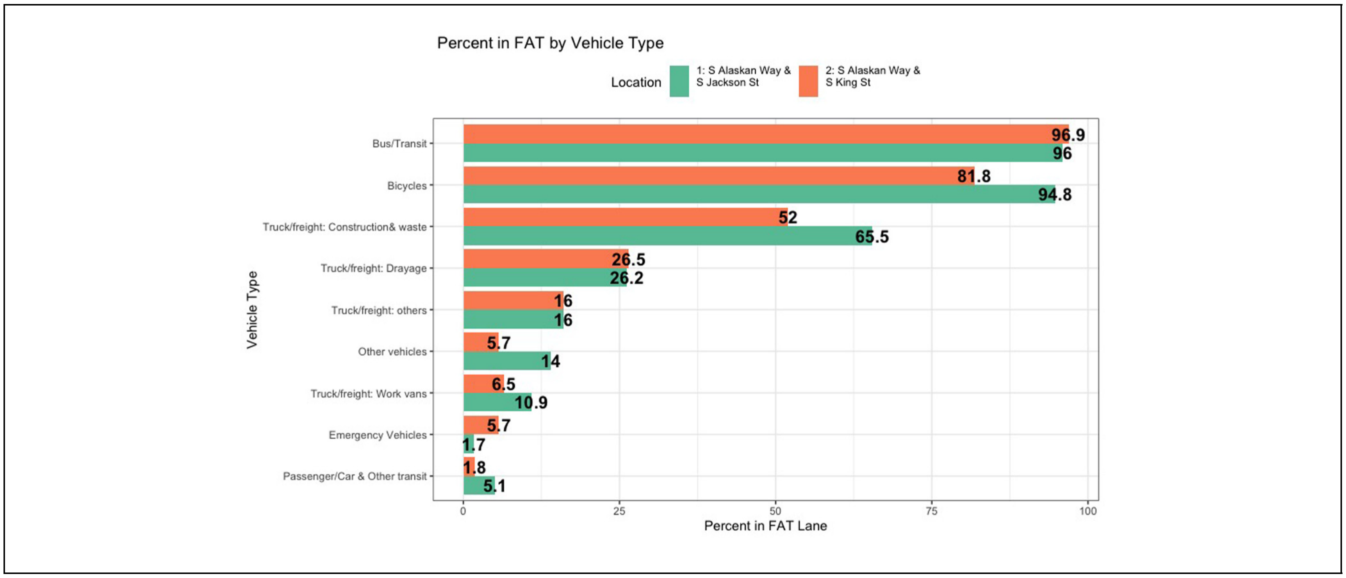

Figure 3. Percent in the freight and transit (FAT) lane by vehicle type.

location, which were much higher ratios than those for drayage vehicles (26.5% and 26.2%). Emergency vehicles, even though they were authorized, had very low compliance rates in the FAT lane. This is possibly because the majority of emergency vehicles in the study area were not responding to emergencies.

Impacts of Congestion

Identifying Congested Periods. Density analysis is conducted for both FAT and general-purpose lanes at two locations as a measure to quantify road congestion. Figure 4 shows the changes in the density measure with time of day (black line) as well as the moving averages (red line). The highest three density values are highlighted in red to indicate the congested periods. For locations 1 and 2, congested time periods are determined as the union of these highlighted sections. The most congested times, which had the highest density values, were observed during the afternoon rush, between 3:00 p.m. and 7:00 p.m., at both locations. The densities during congestion were at least two times the daily averages in both the FAT and general-purpose lanes.

At both locations, lower density values were observed in the FAT lane, indicating that the vehicles in the FAT lane experienced less congestion during the study period, when compared with the vehicles in the general-purpose lane.

Impact of Congestion on Compliance Levels. Table 2 shows the vehicle volumes in both lanes and the percent in the FAT lane, representing the ratio of vehicles choosing the FAT lane for each vehicle type overall and during congested times. Vehicle types that are not authorized in the FAT lane are shown in italic. The change in percent in the FAT lane showed how the parameter changed during congestion in comparison with overall. The overall data included the complete data, 24 h a day for 7 days. The congested data set was the filtered version of the overall data for the congested times determined by the density analysis.

Note: italic = vehicle types that are not authorized in the FAT lane.

The percent in FAT lane increased for the unauthorized vehicle groups comprising passenger cars, other vehicles, and work vans during congested times.

At location 1, work vans (unauthorized) started using the FAT lane 72.3% more during congestion, followed by passenger cars using the FAT lane 49.8% more. The percent in FAT lane increased by 79.0% for drayage vehicles during congestion. In total, including all types of vehicles, the percent in FAT lane increased by 43.2%.

At location 2, percent in FAT lane increased for drayage vehicles increased by 62.7%, during congestion. Other vehicles—a group comprising motorcycles, recreational vehicles and vehicles that failed to be identified—used the FAT lane 133.9% more during congestion. In total, the ratio of the number of vehicles in the FAT lane, increased by 37.4%.

Impact of Congestion on Violator Ratio. Figure 5 shows the changes in the violator ratio parameter, which is the ratio of unauthorized vehicle volumes over the total volume in the FAT lane, with time of day. Average hourly violator ratio was 43.7% and 54.2% at locations 1 and 2, respectively. In Figure 4, the red shaded area shows the

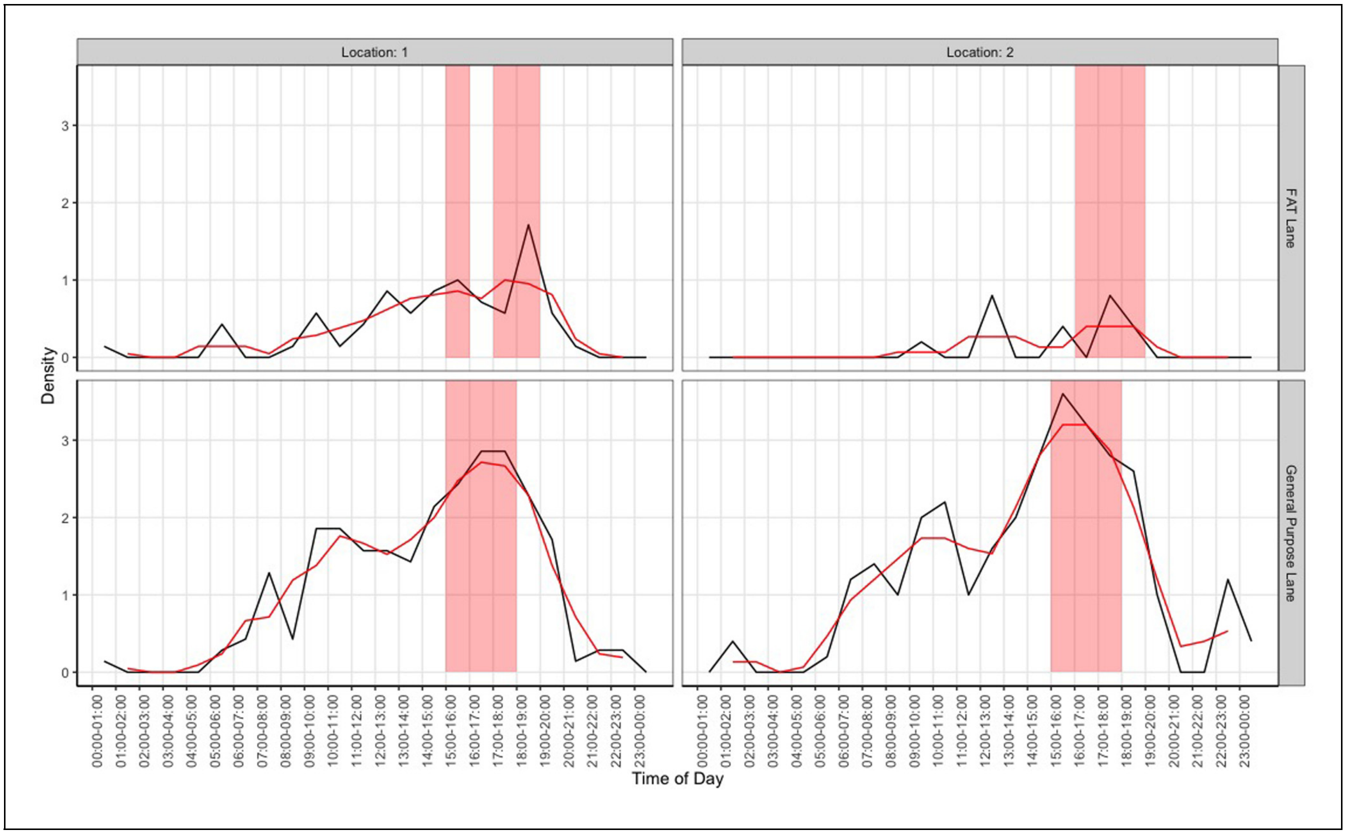

Figure 4. Traffic flow density by time of day.
Note: black line = changes in the density measure with time of day; red line = moving averages; red highlights = highest three density values, indicating the congested periods

Table 2. Percent in the Freight and Transit (FAT) Lane during Congested Times and Overall

Location	Vehicle type	Overall: Total vehicle volume	Overall: Vehicle volume in FAT lane	Overall: Percent in FAT lane (%)	Congestion: Total vehicle volume	Congestion: Vehicle volume in FAT lane	Congestion: Percent in FAT lane (%)	Change (%)
S Alaskan Way/ S Jackson St	Bicycles	727	689	94.8	132	127	96.2	1.5
	Bus/transit	731	702	96.0	670	653	97.5	1.5
	Emergency vehicles	58	1	1.7	6	0	0.0	−100.0
	Other vehicles	*559*	*78*	*14.0*	*119*	*28*	*23.5*	*68.6*
	Passenger/car and other transit	*49,428*	*2,514*	*5.1*	*15,225*	*1,160*	*7.6*	*49.8*
	Truck/freight: construction and waste	809	530	65.5	132	65	49.2	−24.8
	Truck/freight: drayage	225	59	26.2	49	23	46.9	79.0
	Truck/freight: other	1,680	269	16.0	427	70	16.4	2.4
	Truck/freight: work vans	*1,724*	*188*	*10.9*	*543*	*102*	*18.8*	*72.3*
	Total	**55,941**	**5,030**	**9.0**	**17,303**	**2,228**	**12.9**	**43.2**
S Alaskan Way/ S King St	Bicycles	439	359	81.8	112	110	98.2	20.1
	Bus/transit	807	782	96.9	719	711	98.9	2.0
	Emergency vehicles	88	5	5.7	10	0	0.0	−100.0
	Other vehicles	*513*	*29*	*5.7*	*121*	*16*	*13.2*	*133.9*
	Passenger/car and other transit	*53,196*	*960*	*1.8*	*16,668*	*311*	*1.9*	*3.4*
	Truck/freight: construction and waste	1,288	670	52.0	223	88	39.5	−24.1
	Truck/freight: drayage	272	72	26.5	65	28	43.1	62.7
	Truck/freight: other	1,054	169	16.0	238	59	24.8	54.6
	Truck/freight: work vans	*2,108*	*136*	*6.5*	*640*	*52*	*8.1*	*25.9*
	Total	**59,765**	**3,182**	**5.3**	**18,796**	**1,375**	**7.3**	**37.4**

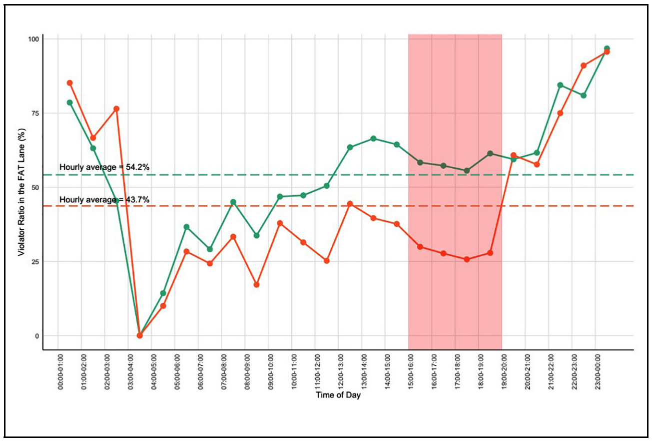

Figure 5. Violator ratio in the freight and transit (FAT) lane by time of day.
Note: long dashed lines = average hourly violator ratios at two locations; red shaded area = congested time period (between 3:00 p.m. and 7:00 p.m.) with the highest density values.

congested time period (between 3:00 p.m. and 7:00 p.m.) with the highest density values, while long dashed lines indicate the average hourly violator ratios at two locations. The hourly violator ratio was observed to be higher than average during afternoon peak hours at location 1, and reached even higher values at night. At location 2, the ratio of unauthorized vehicles in the FAT lane began to increase after 6:00 p.m. while there was congestion. Unauthorized vehicles constituted more than 25% of vehicle volume in the FAT lane for 22 and 20 h at locations 1 and 2, respectively, per day.

Impact on Bus Movement

Traffic volumes were analyzed to inform decision-makers about the possible negative consequences of implementing a FAT lane. The volume and percent in the FAT lane—the ratio of vehicles in the FAT lane over the total volume—were investigated for FAT vehicles specifically and were compared to identify any possible correlation.

The time windows when vehicle volumes increased in the FAT lane did not coincide for trucks and buses. Transit buses constituted 1.30% and 1.35% of total vehicle volume in both lanes at locations 1 and 2, respectively. They were present in the FAT lane during 6:00–10:00 a.m. and 2:00–8:00 p.m., at locations 1 and 2. Transit buses almost always used the FAT lane rather than the general-purpose lane, and they reached their highest volumes during peak hour, around 5:00 p.m.

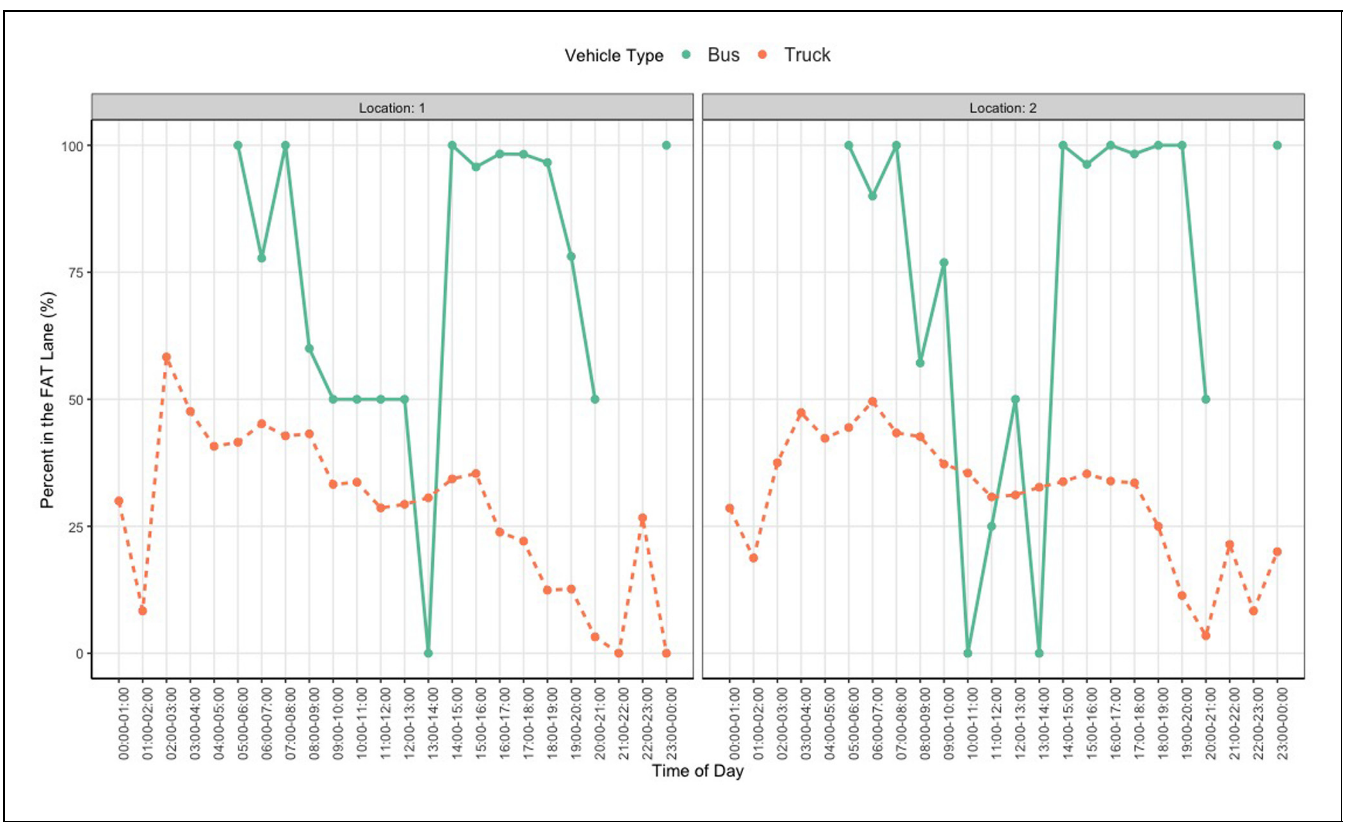

Figure 6. Percent in the freight and transit (FAT) lane by time of day for trucks and buses.

Table 3. Logit Model Results

Alternative	Variable	Coefficient	Standard Error	t-value	p-value
Freight and transit (FAT) lane	Intercept	3.191	0.164	19.441	< 2.20e−16***
FAT lane	Morning	0.302	0.076	3.969	7.23e−05***
FAT lane	Afternoon	0.225	0.077	2.926	0.0034**
FAT lane	Wednesday/Thursday/Friday	0.220	0.066	3.350	0.0008***
FAT lane	Saturday/Sunday	0.200	0.120	1.659	0.0971
FAT lane	Location 1 (base)				
FAT lane	Location 2	−0.403	0.067	−6.058	1.38e−09***
FAT lane	Bus/transit (base)				
FAT lane	Bicycles	−1.241	0.174	−7.123	1.06e−12***
FAT lane	Emergency vehicles	−6.404	0.444	−14.418	< 2.20e−16***
FAT lane	Truck/freight: construction and waste	−3.043	0.149	−20.483	< 2.20e−16***
FAT lane	Truck/freight: drayage	−4.374	0.174	−25.119	< 2.20e−16***
FAT lane	Truck/freight: other	−5.093	0.151	−33.643	< 2.20e−16***
General-purpose lane	Density	−0.221	0.120	−1.839	0.0659
FAT lane	Density	−0.201	0.213	−0.944	0.3452
McFadden pseudo R2					0.377
Log likelihood					−3,526.0
Akaike information criterion (AIC) (fitted model)					7,078.018
AIC (null)					11,315.86

Note: $*p < .05$, $p < 0$, $**p < .01$, $***p < .001$.

Figure 6 shows the changes in the percent in FAT lane parameter during the day for trucks and buses. Trucks used the FAT lane between 5:00 a.m. and 8:00 p.m.; and reached their volume peak at 10:00 a.m. and 2:00 p.m. at both locations. As the utilization (percent in FAT lane) of transit in the FAT lane increased after 1:00 p.m., it decreased for freight vehicles. When buses started to use the FAT lane over the general-purpose lane, some freight vehicles shifted to the general-purpose lane. At location 1, Monday truck utilization in the FAT lane reached its maximum at 24.4%, while the bus utilization was lower than usual over the week, at 89.9%. At location 2, the percent in FAT lane for trucks peaks on Friday, while the percent in FAT is the lowest for buses on the same day.

Logit Model Results

The discrete choice model was developed to identify the factors associated with lane choice. 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. The McFadden pseudo R2 was found to be 0.377, which lies within the desirable range for multinomial logit models. The likelihood ratio test statistic is calculated as 4,261.8 (distributed chi-squared) with a significantly small p-value ($< 2.22e-16$), indicating that the model fits significantly better than the null model. Table 3 shows the summary of results of the discrete choice model.

This model can be used to estimate choice probabilities and give information about the relative importance of the explanatory variables. The reference category in the model was the FAT lane. The logistic coefficient is the expected amount of change in the utility function for each one unit change in the variable. The utility functions are used to calculate the choice probability, and the choice probability increases when the coefficient of the variable increase.

The results demonstrate that buses were more likely to choose the FAT lane over the general-purpose lane than other vehicle types, since the coefficient estimates for each vehicle type are negative compared with buses. Freight vehicles used for drayage purposes 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 over the general-purpose lane for all vehicle types was found to be higher:

- during the morning and afternoon time periods, since they had positive coefficients for the FAT lane alternative
- on Wednesdays, Thursdays, and Fridays in comparison with the other days of the week
- at location 1, which was upstream (north) of the FAT lane.

Discussion and Conclusions

Lane management strategies are implemented to better allocate rights-of-way to promote the most effective use of available road capacity. As freight movements in urban areas increase rapidly, it is essential to understand how, and under which conditions, these strategies can be used to improve lane utilization and mobility. This paper focuses on assessing the performance of a restricted multi-use lane in Seattle, U.S. The objective of this study was to identify metrics to define the efficacy of the FAT lane, explore possible negative implications, and obtain results to guide future implementations.

Analysis of traffic volumes showed that transit buses used the FAT lane at the two locations 96.0% and 96.9% of the time, respectively, and authorizing freight vehicles to use the lane did not affect that lane choice. Some freight vehicles used the FAT lane, but their utilization decreased with increasing numbers of buses in the FAT lane. Freight vehicles had relatively low volumes in both FAT and general-purpose lanes and they opted out of the FAT lane when buses were present. The average bus and truck volumes in the FAT lane peaked at different times and followed dissimilar patterns during the day and the week. Thus, FAT vehicles were largely using the FAT lane at different times of the day and the week and allowing freight vehicles in the bus lane did not deteriorate the transit experience.

The percent of all vehicles in the FAT lane increased by 42.5% and 37.4% for locations 1 and 2, respectively, during congestion. The ratio of violators (e.g., passenger cars, work vans) in the FAT lane is observed to be more than 25% most of the time during the day.

The results of the discrete choice model showed that, for all vehicle types, the probability of choosing the FAT lane was higher during the morning and afternoon hours than during the night, and on Wednesdays, Thursdays, and Fridays as compared with the weekend.

This study uses data gathered from a real-life implementation in Seattle, and contributes to current lane management research, especially with its focus on urban freight movement. A limitation of this study is that the FAT lane implementation was limited to only two block segments, determined by SDOT, and only data from a time period of 7 days was available. It is sensed that high violation rates reflected poor driver education, as it seems many drivers were confused by the FAT lane signage or lack thereof. This is consistent with other pilot studies, such as DfT, and McLeod and Cherrett, which reported that their results were affected by the uncertainty among truck drivers and local characteristics, and the shortness of the road section, respectively (*8*, *9*).

Cities around the world are trying to improve their freight mobility and face similar challenges, such as increasing demand and limited road capacity. This research adds to the evidence that restricted multi-use lane strategies have the potential to tackle these challenges in urban areas.

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Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: A. Goodchild, V. Nemani, S. Gunes, C. Greene; data collection: S. Gunes, C. Greene; analysis and interpretation of results: S. Gunes, C. Greene; draft manuscript preparation: A. Goodchild, S. Gunes. All authors reviewed the results and approved the final version of the manuscript.

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