Bus lane violations: an exploration of causes

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Abstract

Bus lanes have been widely implemented internationally for improving the performance and quality-of-service of surface transit systems. Despite their importance to a city's transit system, bus lanes are frequently violated by road users resulting in subpar service standards. Using extensive field data measurements from Athens, Greece, we analyze violation rates and study their effects on bus lane operational characteristics. Results indicate that: i. reduced perceived enforcement increases violation rates; ii. congestion in adjacent lanes significantly affects bus lane violation characteristics; and, iii. bus speeds are significantly reduced with increased violations.

Keywords: Bus lanes; Violation.

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1. Introduction

Bus systems are widely used because of their relatively low investment and operational cost compared to subway systems, along with their potential for easier network modifications and extensions. However, since buses operate on the existing road infrastructure, traffic and congestion significantly impact their performance and result in lower quality of service and declining ridership. To address this, bus priority measures have been widely implemented in the past few decades to improve the performance and quality of service of surface transit systems; such measures include, for example, exclusive transit corridors (bus ways, bus lanes) and the provision of signal priority. Bus lanes in particular, have been widely implemented in cities worldwide: London and Paris have networks of 240 km and 190 km of bus lanes respectively, while in other cities such as Singapore, Sydney, Berlin and Barcelona bus lanes extend between 70 and 140 km (EMTA, 2009). Bus lane impacts include decreases in bus travel times, increases in bus speeds and reliability improvements (Jacques and

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Levinson, 1997). For example, average bus speed in the Paris bus lanes is 25% higher compared to the rest of the network (RATP, 2009), while bus lanes in London have been associated with a 40% increase in bus ridership (TFL, 2009). Indeed, bus lanes are largely implemented for improving the attractiveness of bus services, increasing bus speeds, improving schedule reliability, and reducing overall emissions (EMTA, 2009; Jacques and Levinson, 1997; RATP, 2009; TFL, 2009).

While exclusive bus corridors are primarily set for transit vehicles, other vehicle categories are frequently allowed to use them (including bicycles, motorcycles and emergency service vehicles), as long as bus traffic is not affected and traffic safety is not compromised. In cities like Paris, Madrid and Rome, taxis, bicycles and motorcycles are allowed to enter bus lanes, while only buses are allowed in Singapore and Stockholm. However, despite the importance of bus lanes to a city's transit and transportation system, transit agencies often face regular bus lane violations by road users (Erikson et al., 1981; Roark, 1982; Stoddard, 1996); for example, drivers tend to illegally enter bus lanes to avoid traffic on congested arterials, while taxi drivers stop to pick-up or drop-off passengers. Bus lane violations are mostly observed on non-segregated bus lanes that are not physically separated from the rest of the roadway (Roark, 1982; Stoddard, 1996).

In this paper we concentrate on the oft-encountered problem of bus lane violations. Our goal is to investigate and identify some of the causes leading motorists to violate bus lanes and quantify the effects on bus movements from these violations. This work will provide some insights and foundations for reducing violations and keeping the high level of service for bus systems.

2. Background

Bus lane violations has been a topic of interest to transit authorities worldwide; however, because of the difficulty in obtaining adequate and reliable data to study the phenomenon, most work has focused on enforcement rather than violations (see, for example, Erikson et al., 1981; Roark, 1982; Stoddard, 1996; Troy, 2004; Schijns, 2006; Martin, 2007; Steer, 2008). A study by Billheimer et al. (1981) examined the impacts of different enforcement strategies, engineering features and education programs on bus lane and ramp metering operations. The authors found that drivers violating bus lanes have a negative perception of lane restrictions and that education programs do not have significant effects on bus lane violations. Sarna et al. (1985) discussed the high violation rates in Delhi's bus lanes, noting that frequently bus drivers found adjacent lanes more attractive! Li et al. (2000) examined the mechanism of automobile behavior intervening into bus lanes, and discussed impacts on bus running. Martin et al. (2006) developed a series of models for forecasting evaluation measures of managed lanes (including bus lanes); violation rates were among those measures considered. Tranhau et al. (2007) modeled the effects of bus lane violations by motorcycles in Hanoi, Vietnam, and found that motorcycle violations have a considerable impact on the operation of bus lanes and particularly on bus speeds, with a pronounced peak during weak enforcement periods. In a recent study, Tsamboulas (2006) proposed an ex-ante evaluation method for measuring the impacts related to the implementation of bus lanes and demonstrated its use by assessing the Athens 2004 Olympic exclusive bus lanes. Overall, research on bus lane violation is limited although it is a common problem for transit agencies in urban areas worldwide; to this end, systematic investigation and analysis of bus lane violations may provide evidence into the mechanism allowing for these violations and offer insights into ways of reducing them.

3. Problem description and dataset

3.1 Problem Description

Athens, the capital of Greece, is a metropolitan area of over 400 km2 and a population of about 4 million inhabitants; the city has one of the largest bus systems in Europe, with over 350 bus lines served by approximately 2500 diesel, CNG and electric buses. The Athens bus network carries over 1.9 million passengers daily and largely covers the transportation needs of the city's inhabitants. The city's constrained road capacity and high vehicle ownership rates have led to heavy traffic congestion problems in several parts of the road network; this has, in turn, considerably impacted the bus system's performance in the city. The Athens Urban Transport Organization (i.e. the Athens Metropolitan Transit Authority) has implemented a bus lane network since the early 1990s with a current length of over 80 km (OASA, 2009). Hours of operation for the Athens bus lanes are weekdays from 6:30 am to 9:00 pm and Saturdays from 9:30 am to 4:00 pm; besides buses, EMS vehicles, coaches, motorcycles and bikes are allowed to enter bus lanes (during operating hours). Recently, a decision was made to allow taxis to enter the bus lanes – during off-peaks, at selected locations and for a two month period - as a pilot study for evaluating the effects of allowing taxis to enter all bus lanes. Finally, we note here that taxis in Athens pick-up and drop-off passengers (almost) anywhere along the road network (similar to New York City).

3.2 Data Collection

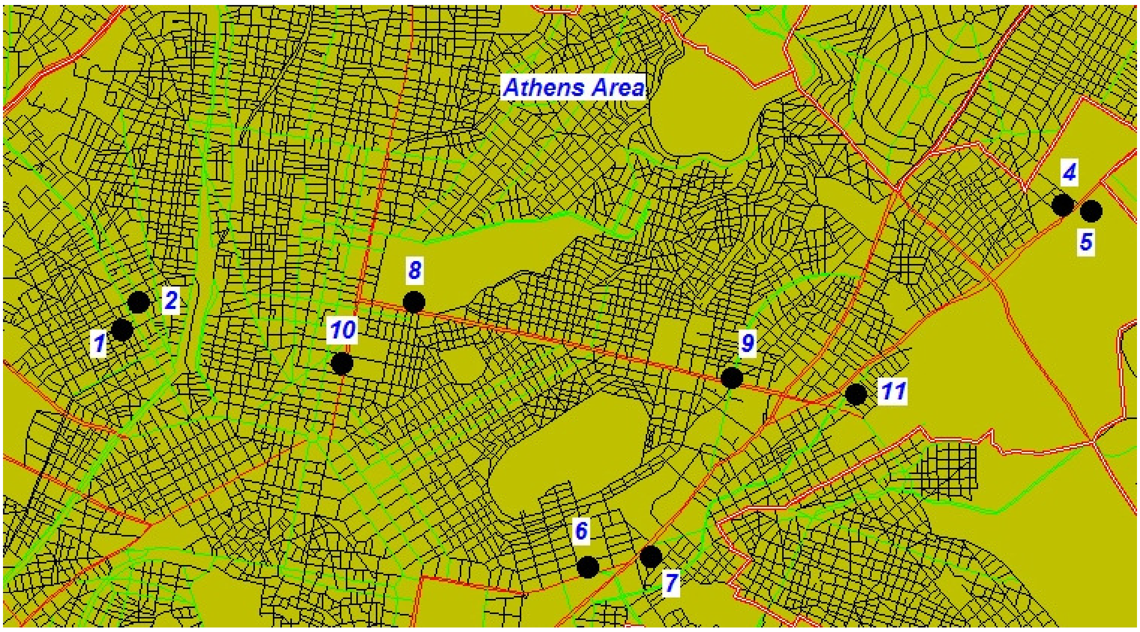

Figure 1: Surveyed downtown and near downtown bus lane locations.

Data was collected through an extensive field survey, over a 3-month period and included sections in eleven bus lanes of the Athens road network, during morning (7:30-14:00) and afternoon periods (14:00-21:00). Counts per vehicle type (private cars, taxis, motorcycles, buses, coaches and trucks) for each bus lane as well as adjacent lanes were collected at 15-min intervals; data on bus speeds were also collected along all bus lanes by measuring travel time needed by buses to traverse constant length segments along these lanes. Survey locations and segments in bus lanes were selected so that no bus stops or queues in right turns would affect flow of buses.

Figure 1 depicts survey locations of examined bus lanes in the downtown area and close suburbs (all bus lanes except for #3, which is located to a more distant city suburb), while Table 1 summarizes information on each bus lane:

Table 1: Details on surveyed bus lanes.

Bus Lane ID (Location)	***Street Name***	***Direction to***	***Lanes per direction (including bus lane)***	***Buses per hour [1,2]***	***Taxis in bus lane per hour [1,2]***	***Violators per hour [1,2]***	***Bus stops in segment***	***Taxis allowed in bus lane***
Bus Lane 1	Lenorman	downtown	2	20±1	76±5	247±5	No	Yes[3]
Bus Lane 2	Lenorman	suburbs	2	19±2	44±5	116±10	No	Yes[3]
Bus Lane 3	Metamorfoseos	downtown	2	26±2	13±4	121±3	No	Yes[3]
Bus Lane 4	Mesogeion Ave	downtown	3	50±4	56±3	157±7	No	No
Bus Lane 5	Mesogeion Ave	suburbs	3	61±2	95±4	294±12	No	No
Bus Lane 6	Vas. Sofias Ave	downtown	3	71±3	37±2	74±3	No	No
Bus Lane 7	Vas. Sofias Ave	suburbs	3	60±1	209±10	422±21	No	No
Bus Lane 8	Alexandras Ave	downtown	3	47±3	67±5	146±12	No	No
Bus Lane 9	Alexandras Ave	suburbs	3	29±2	33±2	73.4±7	No	No
Bus Lane 10	Patision Ave	downtown	2	65±4	27±2	38±2	No	No
Bus Lane 11	Kifisias Ave	suburbs	3	55±3	127±7	280±21	No	No

Notes: [1] Average figures for the period of counts; [2] Based on survey counts; [3] During of peaks and only when passenger are on-board.

Over two thousand observations were collected throughout the survey. In parallel, an additional stated-preference, face-to-face questionnaire based survey took place, in an effort to collect Athens drivers' opinions on the operation and enforcement of the Athens bus lanes. More than 800 local private vehicle drivers and about 200 taxi drivers were asked about their opinions on the purpose of existence, performance and enforcement of bus lanes in Athens. While, this additional survey is not discussed in detail in this study, some of its results are presented in order to support and validate model findings.

4. Preliminary analysis

A descriptive statistics based analysis of collected data was undertaken in an effort to draw some preliminary information on the characteristics of bus lane operations, which would be used in subsequent modeling efforts. For instance, Figure 2 shows the percentage distribution of vehicle – pre category - for bus lanes.

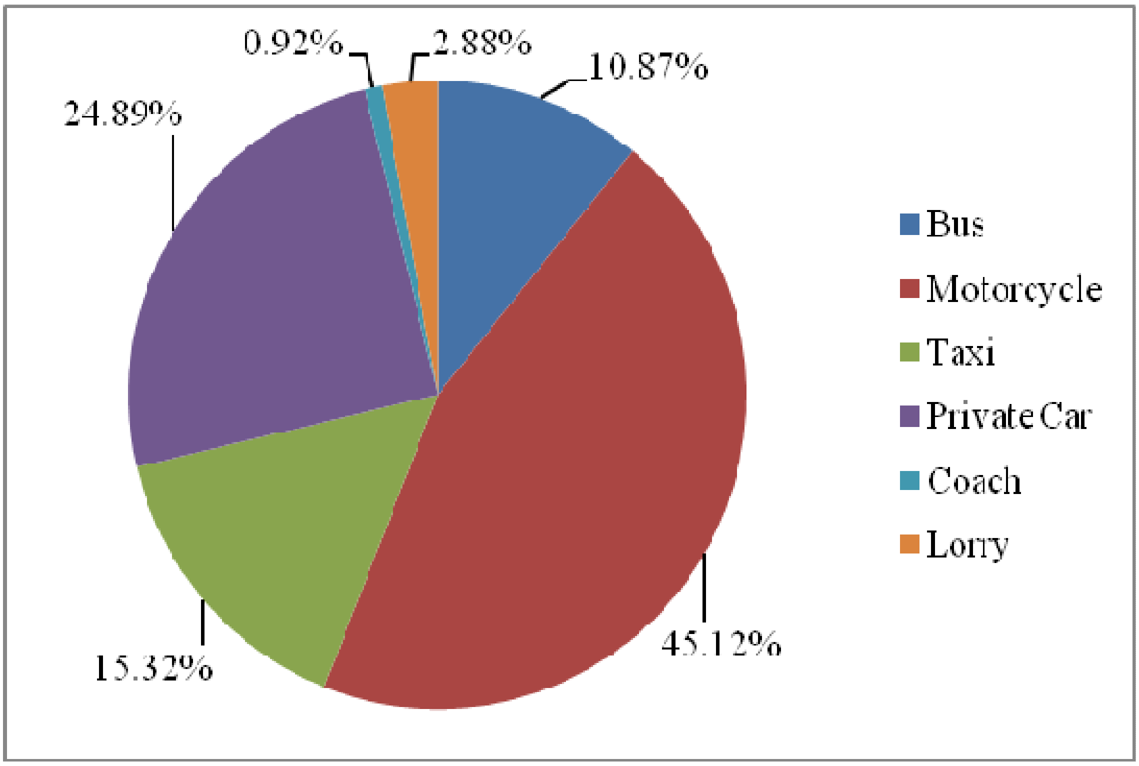

Figure 2: Bus lanes traffic mix (based on field survey).

As can be observed from Figure 2, approximately 43% of vehicles in the bus lanes are taxis, private vehicles and trucks (lorries), all of which are prohibited from using these lanes. Further, a large part of vehicles legally entering bus lanes are motorcycles (45.1%). With over one million motorcycles circulating in Athens on a daily basis, it is safer and faster for motorcycle drivers to use bus lanes than mixing with traffic in adjacent lanes. The distribution of traffic (traffic mix) in bus lanes is an important indicator of violation rates in the lanes, since almost four out of ten vehicles circulating in the bus lanes do so illegally. Figure 3 depicts the percentage of private vehicles and taxis within the bus lane with respect to the total private vehicles and taxis on the entire street (for both the morning and afternoon periods).

According to Figure 3, more taxis and private cars appear to enter bus lanes during the afternoon hours which is a result largely attributed to driver perception of lower enforcement during that period – a fact which will be discussed later on in this section (and particularly in Table 5 findings). We also note that, according to the data collected throughout the survey, a large part of taxis using Athens streets with bus lanes, tend to violate these lanes, while the same percentage for private vehicles is lower (meaning that a lower portion of private vehicles on the same streets violate bus lanes). Furthermore, the survey's traffic counts revealed that the ratio of taxis over private vehicles ranged from 17 taxis/100 private vehicles to 50 taxis/100 private vehicles (with an average of 33 taxis/100 private vehicles), implying that taxis tend to violate bus lanes much more often (in general, taxi drivers are expected to have additional motivation to enter bus lanes to find customers and make easier drop-offs and pick-ups). On the other hand, private vehicle drivers possibly choose to enter bus lanes mostly to avoid traffic congestion, an interpretation supported by the additional questionnaire survey, whose results indicated that over 83% of private vehicle drivers violate bus lanes for that reason. Table 2 shows percentages for all violating vehicles in bus lanes with respect to the total volume in these lanes, while Table 3 shows the percentage of taxis in bus lanes where taxis are allowed.

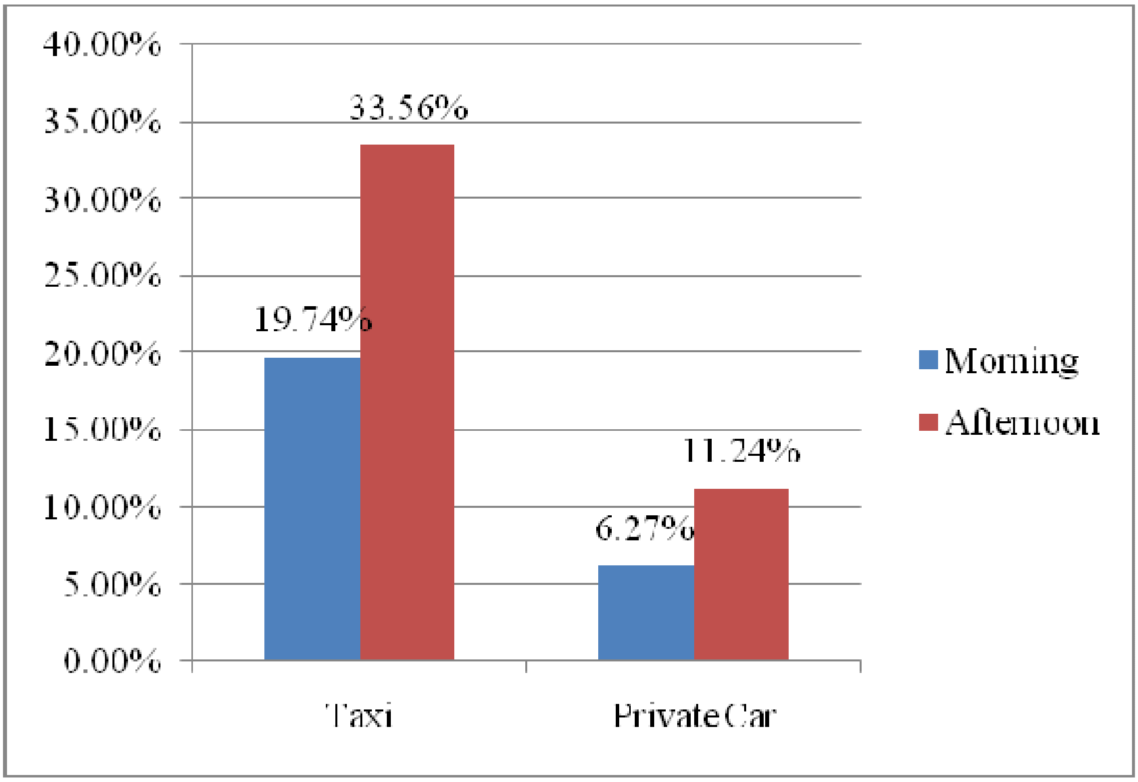

Figure 3: Percentage of private vehicles and taxis within the bus lane with respect to the total private vehicles and taxis on the street (all bus lanes) (based on field survey).

Table 2: Average percentages of violating vehicles with respect to the total volume in the bus lanes.

Bus lanes	***Percentage (%)***
All bus lanes	42.53
Bus lanes where taxis are not allowed to enter	38.41
Bus lanes where taxis are allowed to enter	49.79

Table 2 indicates a high percentage of vehicles violating bus lanes in Athens as was already discussed. In lanes where taxis are allowed to enter, violation are - as expected - higher; however, the high violation percentages clearly indicate that many taxi drivers would use bus lanes regardless of whether it is prohibited or not. Table 3 shows that more than half of the taxis moving along bus lanes use these lanes illegally; interestingly, taxi violations in the afternoon are fewer, a fact possibly attributed to lower demand for taxi services during the afternoon period. Finally, Table 4 summarizes average bus speeds measured during the field survey.

Table 3: Percentage of taxis in bus lanes (where taxis are allowed).

Period	*Percentage (%)*
Morning	59.8
Afternoon	49.18

Table 4: Average (uninterrupted flow) bus speeds measured during the survey.

Bus lanes	*Speed (km/h)*
All bus lanes	22.55
Bus lanes with taxis allowed to enter	24.59
Bus lanes with taxis not allowed to enter	21.61

Further, among those results collected by the supporting questionnaire survey of Athenian private vehicle and taxi drivers, of particular importance is their perception on lane enforcement. It should be noted that main enforcement methods in the Athens bus lanes include violation cameras and police presence. The drivers were asked whether they believe whether there exists enforcement of bus lanes by technological means or police physical presence. Results are summarized in Table 5:

Table 5: Perception of bus lane enforcement.

Perception on enforcement		*Private Vehicle Drivers*	*Taxi Drivers*
Morning Period			
Downtown area bus lanes	Yes	48%	41%
	No	52%	59%
Bus Lanes in suburbs	Yes	35%	24%
	No	65%	76%
Afternoon Period			
Downtown area bus lanes	Yes	42%	40%
	No	58%	41%
Bus Lanes in suburbs	Yes	21%	23%
	No	79%	77%

Table 5 figures indicate that both private vehicle and taxi drivers believe that there is a lack of enforcement in bus lanes, particularly in those located in the suburbs and during afternoon hours. Taxi drivers, whose profession is directly related to the traffic and road environment, are expected to have a better understanding of bus lane enforcement and especially police presence. Their opinion indicates a high perception of lack of bus lane enforcement. As will be noted in subsequent sections of this paper, Table 5 results are in accordance and support model findings.

5. The models

Analysis of individual factors offered in the previous section only gives a basic idea on the operation of bus lanes. However, it is important to jointly estimate those factors that influence some of the operational characteristics of bus lanes. We use Linear Regression, a widely used approach for relating exogenous factors (independent variables) with a given outcome (dependent variable). We note that in developing the Regression models we employ the process outlined in Washington et al. (2003):

1. We used the backward elimination process for selecting the 'optimal' combination of independent variables to be included in the model,
2. We thoroughly examined the estimated models for the four main regression hypotheses: i. zero mean of the error term, ii. normality of the error term, iii. homoscedasticity of the error term, iii. no serial correlation of the error term,
3. Models where all hypotheses of step 2 were met (none violated), were compared, and the one with the highest R2 value was selected as the 'best' model for each of the dependent variables.

In this section we only present the final models for each of the three dependent variables examined (note that all model estimates, error term tests and model development process are available from the authors upon request); those are: i. number of taxis (per 15 min intervals) violating bus lane restrictions; ii. total bus lane violations; iii. average bus speed (per 15 min intervals in bus lanes). In terms of explanatory (independent) variables, location (particular lane 1,2,..,11 location), time period (morning or afternoon), and direction of bus lanes (towards or from the center), could affect violation rates and speeds. For example, perceived enforcement in some bus lanes in the city outskirts is limited compared to the downtown area (as seen in Table 5); the same applies for the time period, a finding already indicated in our preliminary statistical analyses and supported by the additional questionnaire survey results.

As for direction, traffic exiting the city centre (particularly during afternoon peaks), expects lower enforcement in the bus lanes. Traffic volume in adjacent lanes, on the other hand, is the major cause for lane violations; increased traffic and congestion in adjacent lanes, for example, could 'motivate' drivers into (illegally) entering bus lanes. As for bus speeds, apart from bus lane locations and time period, we expect them to be affected by vehicles illegally moving in the bus lanes and, particularly, taxis, suggesting that increased bus lane violations reduce bus speeds in the bus lanes (dependent and explanatory variables used in the modeling effort are shown in Table 6).

Bus lane location is represented by a set of dummy variables where each dummy corresponds to a particular bus lane; similarly, period and direction are both dummy variables. Table 7 presents model results for the total number of taxis in the bus lanes.

According to Table 7 results, more taxis tend to enter bus lanes during the afternoon period since the associated variable (Period) has a coefficient estimate of 7.41; indeed, based upon the supporting questionnaire survey insights, taxi drivers have a perception of lower enforcement at that time and therefore decide to use bus lanes more often. Moreover, during afternoon hours, passengers are usually in a rush to return home and taxi drivers use bus lanes to avoid outbound traffic congestion and rapidly transport them. Increased number of lanes are associated with lower taxi violations (coefficient estimate of -11.1), since taxis have fewer motives to use bus lanes. Traffic in adjacent lanes (coefficient estimate of 0.027) and bus lane locations affect violations, with certain bus lanes appearing as more prone to taxi violations. For example, bus lanes 7 and 8 (with positive coefficients of 41.74 and -7.03) are located in an Athens downtown arterial with considerable traffic problems, while activities along that arterial promote the use of taxis and regular pick-ups along the street; therefore, taxi drivers have a strong motive to enter bus lanes. On the other hand, bus lanes 4 and 5 ((with negative coefficients of -17.96 and -7.59) are located in the city's suburbs, where traffic conditions are significantly better and passengers rarely pick-up taxis on the street. Bus lanes 4 and 5 enjoy markedly higher enforcement, since they are located in an arterial carrying large part of the inbound and outbound traffic during peaks and is thus regularly policed. In addition to the above, increased traffic in adjacent lanes 'urges' taxi drivers to enter bus lanes in an effort to provide better costumer services to their passengers.

Table 6: Dependent and explanatory variables used in the modeling effort.

Dependent Variables	*Possible Explanatory Variables*
– Bus Speed – Number of all vehicles violating bus lanes – Number of all taxis in bus lanes	– Bus lane location, represented by a dummy variable indicating each particular lane. For example, variable "Bus Lane 4" takes the value of 1 if the corresponding counts refers to that bus lane. – Period (0 for morning, 1 for afternoon) – Number of traffic lanes on the street per direction (including bus lanes) – Direction (0: to the downtown area, 1: to the city suburbs) – Traffic volume in adjacent lanes – Taxi traffic volume in adjacent lanes – Ratio of taxis in the bus lane to taxis in adjacent lanes – Number of private vehicles violating bus lanes – Number of taxis in bus lanes

Table 7: Model results for taxi entrances in all bus lanes.

Explanatory variables[1]	*Coefficient value*	*t-statistic*
Constant term	22.32	8.43
Period	7.41	11.84
Number of traffic lanes	-11.10	-9.30
Traffic volume in adjacent lanes	0.027	6.41
Bus Lane 4	-17.96	-12.78
Bus Lane 5	-7.59	-5.82
Bus Lane 7	41.74	30.49
Bus Lane 8	7.03	5.44
Number of observations	2121	
R^2	0.712	

Note: [1] non significant variables (at the 90% confidence level) are omitted.

Model results for the total number of bus lane violations are shown in Table 8.

Table 8: Model results for total bus lane violations.

Explanatory variables [1]	***Coefficient value***	***t-statistic***
Period	26.57	16.87
Number of traffic lanes	-41.65	-13.88
Traffic volume in adjacent lanes	0.07	6.76
Bus lane 4	-31.06	-8.80
Bus lane 5	4.37	1.33
Bus lane 6	-3.48	-0.81
Bus lane 7	77.88	22.62
Bus lane 8	17.14	5.27
Number of observations	2121	
R^2	0.635	

Note: [1] non significant variables are omitted.

Again, similar to the previous model presented in Table 8, period and number of lanes of the roadway appear to significantly affect bus lane violations by all vehicles. During the afternoon period, perception of enforcement is limited (as indicated by the questionnaire survey results) and drivers risk less when entering these lanes. The number of bus lanes, on the contrary, has a negative effect on vehicle violations (coefficient estimate of -41.65): more lanes provide better traffic flow and make it more difficult for left lane drivers to use the bus lanes, commonly located on the right side of the street. As for traffic volume on adjacent lanes, when it increases drivers tend to violate bus lanes to avoid traffic at higher rates (coefficient estimate of 0.07). Similar to the case of taxis (Table 7), some bus lanes tend to have larger violation rates compared to others. Bus lane 6 in particular, located in the city's main downtown arterial where enforcement perception is very high, appears to have lower violation rates since drivers are more reluctant to using it. Finally, model results for bus speeds in the bus lanes are reported in Table 9.

Table 9 results indicate that (15 min interval average) speeds, in general, are highly affected by the location of specific bus lanes. To this end, specific bus lane locations have a statistically significant impact on speeds (see the coefficient estimates for all bus lanes); this is, a-priori, expected since some bus lanes have better geometric characteristics (width and so on) and pavement conditions. In particular for bus lanes 4 and 5, the distance between intersections is larger and lanes are wider yielding a potential for higher average bus speeds; on the other hand, bus lanes 6, 8, 9, 10 are located on arterials at the city downtown area where land use and roadway characteristics do not allow for higher speeds.

Direction and period also affect speeds in the bus lanes. Buses moving to the city centre seem to have lower speeds, a finding possibly related to the traffic conditions when entering the city centre, while speeds during the afternoon period are higher since at that time traffic volume decreases. As expected, yet not explicitly quantified in previous research, volumes of private vehicles and taxis in the bus lane have a negative effect on bus lane speeds. Coefficient estimates for these two variables are -0.15 and -

0.41 respectively, making it clear that, as additional vehicles use the bus lanes, buses have to operate at lower speeds. To this end, the coefficient estimates indicate that for each additional taxi violating the bus lane, average bus speed is reduced by approximately 0.4 km/hr (every 15 min); considering that violating taxis can easily exceed 20 vehicles per 15 min (see Table 1), this suggests that average speeds can be reduced by almost 2km/hr (corresponding to a 10% speed decrease).

Table 9: Model results for bus speeds.

Explanatory variables[1]	*Coefficient value*	*t-statistic*
Constant term	33.71	49.21
Direction	-1.02	-2.04
Period	2.68	7.46
Taxis in adjacent lanes	-0.15	-2.58
Taxis in the bus lane	-0.41	-5.32
Private vehicles in the bus lane	-0.32	-4.73
Bus Lane 4	5.49	7.14
Bus Lane 5	8.36	13.69
Bus Lane 6	-4.47	-4.92
Bus Lane 8	-1.73	-2.78
Bus Lane 9	-3.55	-5.80
Bus Lane 10	-11.82	-14.49
Number of observations	2121	
R^2	0.50	

Note: [1] non significant variables are omitted.

Moreover, the effect of taxis is larger compared to the overall number of vehicles, possibly because taxis enter and move slowly in the bus lanes to drop-off and potentially find and pick-up passengers along them; this behavior has a significantly higher (negative) impact on bus speeds. This model also indicates that the traffic volume on adjacent (to the bus lane) lanes is an important determinant of bus speeds on the bus lane; we attribute this finding to the 'motive' drivers have to violate bus lanes when traffic is higher on adjacent lanes.

6. Conclusions

The goal of this paper was to investigate and identify some of the causes leading motorists to violate bus lanes and quantify the effects on bus movements resulting from these violations. Findings from this study may provide some insights for reducing violations and keeping high level-of-service in bus services. The analysis of bus lane violations was done based on data collected through an extensive field survey undertaken in sections of the Athens, Greece, bus lane network. The results indicated that bus lane violations may be attributed, at least to a large extent, to increased traffic in the adjacent lanes; the perception of limited – or reduced - enforcement (validated by a supplement study) is an additional significant contributor of violations while on streets with fewer lanes violations are higher.

The results clearly suggested that increased bus lane violations lead to reduced bus speeds. Quantifying this effect suggested that average bus speed is reduced by approximately 0.4 km/hr for each additional taxi violating the bus lane and, considering that violations frequently reach 20 taxis per 15 min, average bus speeds can be reduced by almost 2km/hr , which corresponds to a 10% bus speed reduction. Furthermore, we should note that the proposed methodology and results could be applicable for other cities with similar traffic conditions and taxi operations, as well as limited enforcement. Overall, we believe that increased enforcement is a strong requirement for improving bus lane operations and reducing violations, while permission for taxis as well as motorcycles entering bus lanes must be reexamined.

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