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Assessment of Bus Lane Violations in Relation to Road Infrastructure, Traffic and Land-Use Features: The Case of Thessaloniki, Greece

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Abstract

The implementation of bus-lane systems is promoted by the EU common transport policy framework as a tool towards sustainable urban mobility. However, the effectiveness of the bus-lane system in terms of both the performance of the public transport system and the decrease of private car dependency can be compromised by unauthorized traffic. The purpose of the current paper is the investigation of the interaction between the features of road infrastructure, traffic flow and urban land use with the bus-lane violations. More specifically, a system of indicators is developed in order to examine the impact of the above features on unauthorized traffic. Based on real-time measurements and descriptive data, the proposed system comprises a useful tool for local stake-holders, which can be adapted to a city's specific characteristics. In addition, a pilot application is conducted for the bus-lane system of Thessaloniki leading to useful conclusions and a framework for strategic priorities.

Keywords: Bus-lane; Violation; Road Infrastructure; Road Traffic; Land Use; Indicator System.

1. Introduction

Two decades after the emergence of sustainable mobility principles, the dominance of the private car remains a definitive factor of the urban transport problem. In order to cope with the problem, scientists, planners and policy makers continue to combine their efforts towards the promotion of public transportation. It should be pointed out that the efforts for the enhancement of the public bus system face an additional challenge in comparison to fixed route systems (such as tramways and metro systems), as the bus shares the road infrastructure with private vehicles. Furthermore, due to the high density of the urban road network, the public bus network has the ability to cover extended urban areas and provide linkages between other transport modes in the context of urban co-modality. Thus, in many cities of the world and the majority of European cities, the

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public bus system plays a key role in daily commuting. For example, in 2006 the 8.3% of the total passenger-kilometres generated in the European Union (EU27) referred to transport by bus or coach, presenting a total growth of approximately 5% since 1995 (EC, 2006). In some European countries, such as Greece, the annual number of passenger-kilometres per inhabitant performed by public bus was 1.8 times higher than the European Union's (EU27) average (Eurostat, 2009).

A common measure towards the enhancement of the performance of the public bus is the development of its own fixed track by designating part of the existing road infrastructure as a bus-lane. The implementation of bus-lanes aims at the improvement of the operability and reliability of the bus system by providing congestion-free conditions along main road corridors with the goal of strengthening its attractiveness in comparison to the private car and improving the environmental and safety conditions (Waterson, Rajbhandary, and Hounsell, 2003). Towards this purpose the 1992 EU Transport White Paper proposes the use of bus-lanes as a strong policy instrument for the discouragement of private car use in congested urban areas during peak periods (EC, 1992). Thus, in the next decade, local authorities implemented bus-lane networks in many European cities (EC, 2001). The Green Paper on Urban Mobility highlights some of these local initiatives, such as the 'flexible' bus-lanes of Barcelona, as good practices and also suggests that such initiatives should be based on integrated transport planning that contributes to the development of a high quality urban environment. Furthermore, in the rise of global economic recession, the Green Paper proposes the implementation of bus-lanes in combination with the appropriate priority measures in the context of a bus rapid transit system as an alternative to the more expensive urban railway systems (EC, 2007).

However, the introduction of bus-lanes in urban areas is dated long before the emergence of sustainability principles. Worldwide, the first designated bus-lane was implemented in the city of Chicago, USA in 1939 (APTA, 2004). In Europe the first bus-lane network was implemented in Hamburg, Germany in 1962. Two years later the use of bus-lanes was introduced in France and six years later in the United Kingdom. The first contra-flow bus-lane in the world was established in France in 1966 (Jiang, Xue, and Li, 2010). Nowadays, there are various options for the implementation of bus-lanes deriving by the appropriate combination of the following features (Miller, 2009):

1. Placement (along the curb or the centre lane),
2. Direction of flow (following the traffic flow or contra-flow),
3. Use (dedicated bus-lanes or mixed use with high occupancy vehicles (HOVs), taxis, two-wheelers and/or goods delivery vehicles),
4. Separation from traffic (permanent infrastructure, physical barriers, markings etc.),
5. Schedule (full-time or during peak periods) and
6. Traffic control (prioritization at intersections, right turns) and enforcement methods.

As regards the design of the bus-lane, Levinson et al. (2003a) suggest that in the case where buses operate on protected or fully separated road infrastructure, the level of service provided can reach the level of service provided by metro systems; in the case where buses operate simultaneously on various types of road infrastructure, the level of service can reach this of light rail systems and in cases where buses operate mainly in mixed traffic conditions, the level of service can reach this of tram or streetcar systems.

Despite the wide international experience and the availability of various options for their implementation, the effectiveness of the bus-lane network and its contribution to sustainable mobility is degraded in many cases due to traffic violations. These violations, which are mainly observed along axes with heavy traffic and central areas, usually refer to the use of the bus-lane by unauthorized vehicles for traffic or short-term parking/stopping purposes (Pitsiava-Latinopoulou, Babsas, and Andrianos, 2006). In these cases, buses are forced to merge back into traffic causing negative impacts on the operability of the public bus system as well as on the overall road safety and level of service (NRC, 2008).

The current paper attempts to investigate how various factors affect bus-lane traffic violations. More specifically, factors such as the geometrical, operational and traffic characteristics of the road (including the bus lane) and the type and intensity of the adjacent land uses are analysed in depth and their influence on unauthorized traffic is examined. Towards this purpose, an indicator system is proposed based both on real-time traffic measurements and descriptive data. This system is then applied to Thessaloniki's bus-lane network, which comprises non-separated lanes with a low level of traffic enforcement. The proposed methodology is flexible for adaptation to various cases providing a useful insight to local decision makers, planners and stakeholders as far as the integration of bus-lanes with the urban environment is concerned.

2. Research background

A number of research efforts have been conducted worldwide concerning the introduction, implementation and management of bus-lanes. Along with the appropriate legislation, guidelines for planning and implementation have been formed in order to promote safe and efficient bus-lane networks in the general context of multimodal urban transit development (Levinson et al., 2003b; APTA, 2004).

Within the existing urban transport policy framework the following distinctive and interrelated aspects concerning the bus-lane implementation process can be recognized:

1. Focused policy strategies for bus-lanes,
2. integrated planning process,
3. appropriate infrastructure design and development,
4. sustainable management and operation and
5. effective enforcement.

Possible weaknesses in one or more of the above steps may lead to the common phenomenon of traffic violations, having a negative effect on the overall performance of the system. The improvement of the operational efficiency of existing systems relies on actions strengthening one or more of the foretold aspects, depending on the system's specific characteristics and needs (Kiesling and Ridgway, 2006).

Various research techniques have been used in order to investigate the effect of bus-lanes on the road traffic conditions. Thus, the evaluation of the San Francisco bus-lane network showed that the appropriate design and operation of the bus-lane network (i.e. the chosen type and placement of the bus-lanes, the standardization of operating schedule, the integration of urban landscape and road infrastructure) can increase its effectiveness by enhancing the overall performance of the system (Kiesling and Ridgway, 2006). Furthermore, cost/benefit analysis has been extensively used by

various agencies in order to calculate the effectiveness and cost-efficiency of bus-lane systems. In these cases, financial, operational and environmental factors have been taken into account, in order to calculate the performance of the examined infrastructure via countable characteristics such as delays and ridership (TRB, 2011).

In Greece, the introduction of bus-lanes was followed by a number of studies which highlighted their substantial effect on traffic conditions and the dependence of their effectiveness on the actual conditions of management and operation (Tsamboulas, 2006). More specific, the comparison of field data concerning mean travel speed and time referring to the periods before and after the implementation of exclusive bus-lanes along main arteries of Thessaloniki showed that the introduction of bus-lanes resulted to a marginal improvement of the public bus system's performance (Mintsis, Taxiltaris, and Proios, 1998). On the contrary, a traffic simulation model implemented by (Basbas, Stamos, and Kitis, 2011) for the case of a contra-flow bus-lane introduction along a main artery of Thessaloniki showed that the improvement of the bus-lane's performance is counter-balanced by the increase in pollutant emissions and fuel consumption due to the decrease of road capacity.

A significant research effort has been also conducted towards the investigation of the impact of traffic incidents (including drivers' illegal activity) on the bus-lane operation. For example, the impact of traffic incidents has been examined through modelling in order to achieve optimal bus fleet management and dynamic operation (Polyviou, Hounsell, and Shrestha, 2012). It was found that there is a linkage between the performance levels of the bus-lane system and the means and intensity of traffic enforcement, a fact that augments the need for a reliable control system. Thus the establishment of an effective enforcement environment (either active or passive) could lead to better operational results through securing the working conditions that were introduced during the planning process (Agrawal, Goldman, and Hannaford, 2012) and actively contributing towards the promotion of public transport use and the long term improvement of the urban environment (Pitsiava-Latinopoulou, Babsas, and Andrianos, 2006). As the mobility conditions and the transport system's level of service continue to be significantly lowered by bus-lane traffic violations (Kepaptsoglou, et al., 2011), the parameters that lead to the illegal use of bus-lanes should be further examined.

3. Methodology

The present research aims at the assessment of the impact of the main parameters related with the operational and traffic characteristics of the road segment (including the bus lane) and the type and intensity of the adjacent land uses on the number of bus-lane violations. Towards this purpose the following methodological approach is recommended:

1. Observation and identification of the specific factors of traffic, road infrastructure and land use that may affect traffic violations along the examined bus-lane network
2. Formulation of an indicator system in order to quantify the selected factors, which will constitute the input database in a cross-examination with the features of bus-lane violations.
3. Application of the indicator system and extraction of conclusions concerning the impact of various factors on bus-lane violations.
4. Setting up of strategies for the discouragement of bus-lane violations.

3.1 Identification of parameters

Taking into consideration the existing literature as well as on-site observations the main parameters that influence travel behaviour and lead to violations can be categorized into three thematic fields concerning:

1. Road infrastructure
2. Traffic features
3. Land use characteristics.

The first two thematic fields refer to both the total road section and the bus-lane. The land uses that are taken into account are those within a walking distance from the bus-lane. The parameter of traffic enforcement is another definitive factor of bus-lane violations, which is extensively examined in the international literature as well as in previous research activities referring to the bus-lane network of the case study.

3.2 Formulation of the indicator system

The quantification of the above parameters can be conducted by the implementation of a system of indicators in a way that could reflect their impact on bus-lane violations and be flexible for adaptation into various cases. Thus, the implementation of the indicator system comprises the following steps:

1. Selection of the appropriate spatial and time reference according to the purpose of the study
2. Allocation of the suitable data sources and development of the appropriate calculation methods (described by technical sheets)
3. Calculation of indicators and
4. Synthetic analysis of the results and extraction of conclusions

The proposed indicators for each thematic field are summarized in Table 1 and described in detail in the technical sheets of Appendix 1. These indicators derive from the cross-examination of the identified parameters with the bus-lane violations' features (see indicators' description) and thus embody the impact of each examined parameter on the level of violations.

Table 1: Identification of main parameters.

Thematic field	***Indicator***	***Spatial reference***
Road infrastructure	INFR.1. Bus-lane type and infrastructure INFR.2. Road classification and infrastructure INFR.3. Range of road capacity	road segment, bus-lane segment
Road traffic	TRAF.1. Daily and hourly traffic volume TRAF.2. Traffic composition TRAF.3. Mean speed	road segment, bus-lane segment
Land use	LAND.1. Land use intensity	buffer zone (walking distance around the bus-lane)

According to the calculation method described in the technical sheets, the assessment of the indicators is based on the appropriate combination of on-site measurements and observations, statistical data and framework analysis. Furthermore, the indicators included in the Thematic Fields (INFR) and (LAND) are assessed using data from Thematic Field (TRAF). The combination of data requirements for the assessment of the indicators for each thematic field is presented in Figure 1. The light-blue arrow represents data input within the indicator system and the dark-blue arrow represents data input from external sources.

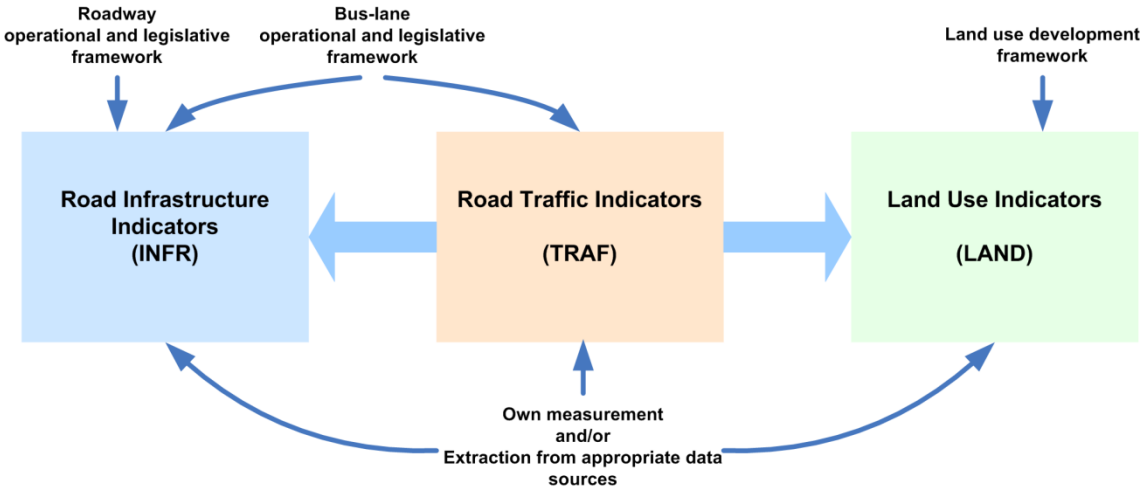

Figure 1: Data requirements for the implementation of the indicator system

4. Case study

4.1 The study area and the examined bus-lane network

Thessaloniki is the second largest city in Greece and one of the biggest urban centres in the Balkans. The concentration of population and activity in Thessaloniki imposes significant pressures on the city's transport system, which is mainly dependent on road transport. According to recent studies, approximately one out of two city residents owns a car (Pitsiava-Latinopoulou, 2008). Car dependency leads to the congestion of main arteries. The latest General Transport Study (completed in the year 2000) shows that the city centre of Thessaloniki is the origin or/and destination of the 25% of approximately 2.3×10^6 daily trips. The only available public transport system is the bus system, which accounts for approximately 180×10^6 passenger boardings annually. In the future, the eminent operation of the Metro system (which is expected to service 250,000 passengers/day), the gradual expansion of the city's bicycle network and other interventions which are at the stage of planning or consultation (i.e. tramway system, coastal transport, outer orbital highway) are expected to alleviate congestion from the city's road network (Gavanas et al., 2012).

The public bus network of Thessaloniki extends throughout the city linking the outskirts and the peri-urban areas with the city centre and the other main poles of activity (e.g. transport terminals, hospitals, large scale commercial and recreational land uses etc.). The majority of the network uses the same road infrastructure with the rest of traffic and, thus, it is subject to traffic delays and congestion. It comprises four segments along each of the following arteries: V. Olgas St., Egnatia St., Tsimiski St. and Mitropoleos St., which accommodate a significant number of commuting trips

towards and throughout the city centre. It should be highlighted that Tsimiski St. and Mitropoleos St. are located in the Central Business District (CBD); Egnatia St. is located at the northern edge of the CBD while V. Olgas St. is the main artery that leads directly from the eastern residential areas to the CBD Figure 2. Currently, there are 11 bus-lines that pass through V. Olgas accounting for a total volume of 393 buses/day, 15 bus-lines (834 buses/day) through Egnatia St., 13 bus-lines (602 buses/day) through Tsimiski St. and 9 bus-lines (527 buses/day) through Mitropoleos St.

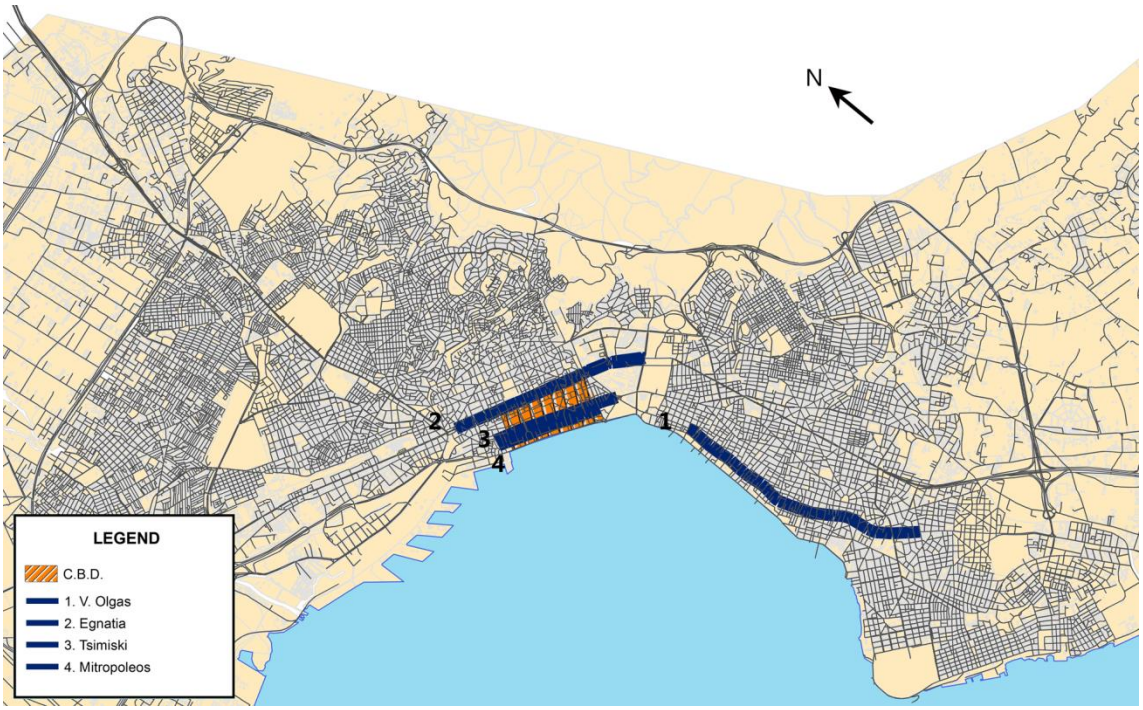

Figure 2: Examined bus-lane network and CBD

The network comprises bus-lanes located along the curb and separated from the rest of traffic by horizontal signing and sign posts and have the same direction with the rest of the traffic (there are no contra-flow bus-lanes). There is no prioritization program for the bus-lanes at signalized intersections. It should be also mentioned that there are no pavement slots at bus-stops. According to the Public Bus Authority's Administrative Council (Decision 1997/2000 14.12.2000), the schedule of the bus-lane network's operation is presented in Table 2. The network was initially developed for the exclusive use by public buses and later on, according to the decision of the Ministry of Transport and Communications, taxis were also permitted during the on-going construction of the city's Metro system except for the periods from 06:30 to 09:30 and from 14:00 to 17:00 (Government of the Hellenic Republic, 2007). Furthermore, the use of bus-lanes is prohibited for all other types of vehicles (loading/unloading vehicles, light and heavy duty trucks, private cars, P2W, bicycles etc.).

The bus-lane network's traffic surveillance and enforcement is conducted by a system of analogue and digital cameras located along the pavement as well as by traffic police patrols (Pitsiava-Latinopoulou, Babsas, and Andrianos, 2006). However, the system of cameras is not functioning effectively. Moreover, the research team's observations during the morning and evening peak periods showed that the traffic police's presence along the bus-lanes is relatively scarce and has limited effect on unauthorized traffic.

Thus, the current level of traffic enforcement along the bus-lanes is considered to be low.

Table 2: Scheduled period of bus-lanes' operation.

Bus-lane segment	***Daily period of operation***
V. Olgas	From 06:30 to 20:30
Egnatia	From 06:30 to 20:30
Tsimiski	From 06:30 to 20:30
Mitropoleos	From 10:00 to 22:00

The insufficient level of traffic enforcement along Thessaloniki's bus-lane network accompanied by the prevailing road infrastructure conditions, traffic characteristics as well as the type of the adjacent land uses results to a large number of bus-lane violations by all types of road vehicles. Thus, the objective of the present case study constitutes the investigation of the way that the features concerning the thematic fields of road infrastructure, traffic characteristics and type of land-use are linked with the unauthorized traffic along Thessaloniki's bus-lanes through the application of the proposed indicator system.

4.2 Surveys and other data sources

In order to test the applicability of the above methodology a case study was conducted for the bus-lane network of Thessaloniki. More specific, the case study focuses on selected representative segments (between signalized intersections) of the four axes of the city's bus-lane network, based on the information obtained from a GIS database and on-site observations. For the calculation of traffic volume, a system of road surface traffic counters (i.e. vehicle magnetic imaging traffic analysers) was used, which were programmed to conduct distinct measurements for specific ranges of vehicle length according to the vehicle category Table 3. The measurements were conducted during three workdays (Wednesday to Friday) and mean values were extracted. Data for transport infrastructure and land use features derived from the available GIS database at the Transport Engineering Laboratory. Finally, information about the operation of the bus-lane network and the public bus system was provided by the Thessaloniki's public bus operator (OASTH) and the Thessaloniki's public transport authority (ThePTA).

Table 3: Vehicle categories and speed range of on-site measurements.

Range of vehicle length (m)					
0.0 – 2.9	3.0 - 6.0	6.1 – 9.3	9.4 – 13.0	13.1 – 18.5	≥ 18.6
Corresponding vehicle category					
Power 2 Wheelers (P2W)	Car	Light Truck	Heavy Truck	Bus	Other

4.3 Calculation of indicators and assessment of their impact on violations

4.3.1 Road infrastructure indicators

The examined bus-lane network comprises four axes with bus-lanes of the same type and similar infrastructure and thus the implementation of the indicator concerning the bus-lane type and infrastructure (INFR.1) is omitted as it cannot lead to any comparable conclusions concerning the way that the bus-lane's characteristics affect unauthorized traffic. In the following, the impact of the indicators INFR.2 (Road classification and infrastructure) and INFR.3 (Range of road capacity) on the bus-lanes' unauthorized traffic volume are examined. The results of this analysis are given in Table 4 and Figure 3 respectively.

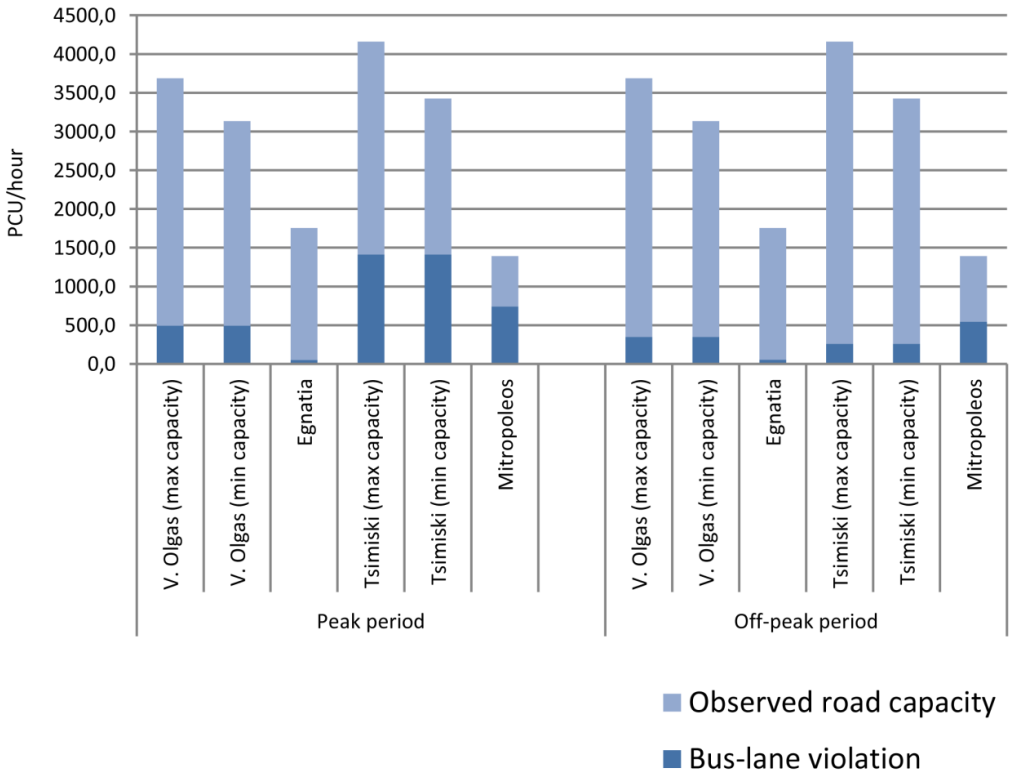

Figure 3: Unauthorized bus-lane traffic as share of the road's observed capacity

More specifically, Table 4 shows that the share of unauthorized bus-lane traffic in the road's total daily traffic varies from 3%-52.5% along the examined roads. The great number of violations along Mitropoleos St. is due to the fact that, apart from the bus-lane, the specific road has only one lane, serving a relatively high traffic volume. In addition the bus-lane in the examined road segment is separated by a series of reboundable bollards, while the existence of illegal parking in the preceding road segment forces traffic to enter into the bus-lane. On the other hand, Egnatia St. presents the lowest daily share of bus-lane unauthorized traffic due to the Metro system's construction sites along the road, which result to the frequent interruptions of the bus-lane. The other two roads (i.e. V. Olgas St. and Tsimiski St.) present similar shares of unauthorized traffic in relation to their daily traffic.

For the calculation of the indicator INFR.3 (Range of capacity) the impact of illegal parking along the pavement opposite to the bus-lane on the values of road capacity was taken into account and thus it resulted to two possible values of road capacity:

- Maximum (for conditions without illegal parking) and
- Minimum (for conditions with illegal parking).

Table 4: Road classification and infrastructure in relation to the share of unauthorized.

Features	***Bus-lane network***			
	V. Olgas	Egnatia	Tsimiski	Mitropoleos
Classification	Main artery	Main artery	Main artery	Secondary artery
Width (m) / Effective Width (m)	16/16	16/16 (8/8 per direction)	14/14	10/10
Direction (E-W, W-E, 2Way) *	E-W	2Way	E-W	W-E
Number of lanes/ direction (including 1 bus-lane)	3	3 per direction	4	2
Center island (Yes, No)	No	No	No	No
Type of intersections (Signalized, Traffic signs, Roundabout, Other)	Signalized	Signalized	Signalized	Signalized
Unauthorized traffic (% of the road's total daily traffic in PCU/day)	**20.5**	**2.9**	**18.5**	**52.8**

* E-W=East to West, W-E=West to East, 2Way=Two way road.

The results from the implementation of the indicator are presented in Figure 3, where it can be seen that the highest shares of unauthorized bus-lane traffic in relation to capacity occurs during the peak-period along the arteries of the CBD (i.e. Tsimiski St. and Mitropoleos St).

4.3.2 Road traffic indicators

The implementation of the indicator TRAF.1 (Daily and hourly traffic volume) for each of the selected arteries is presented in Figure 4. It can be observed that the unauthorized traffic flow along the bus-lane follows the same pattern with the road's overall traffic flow, whereas the authorized bus-lane traffic (public buses and taxis within the legislated time schedule) presents a more stable pattern.

In order to further examine the pattern of the relation between the bus-lane's unauthorized traffic and the road's overall traffic, a synthetic indicator of 'Weighted average hourly traffic volume' was developed based on TRAF.1. The calculation of this indicator is presented in the Figure 5, where it can be seen that the lowest percentages and smallest range of unauthorized traffic are presented along Egnatia St., while the highest percentages and the widest range along Mitropoleos St. Furthermore, it can be observed that the majority of bus-lane violations occur when the road's hourly traffic volume is in the range of 100%-150% of the road's daily mean hourly average traffic volume.

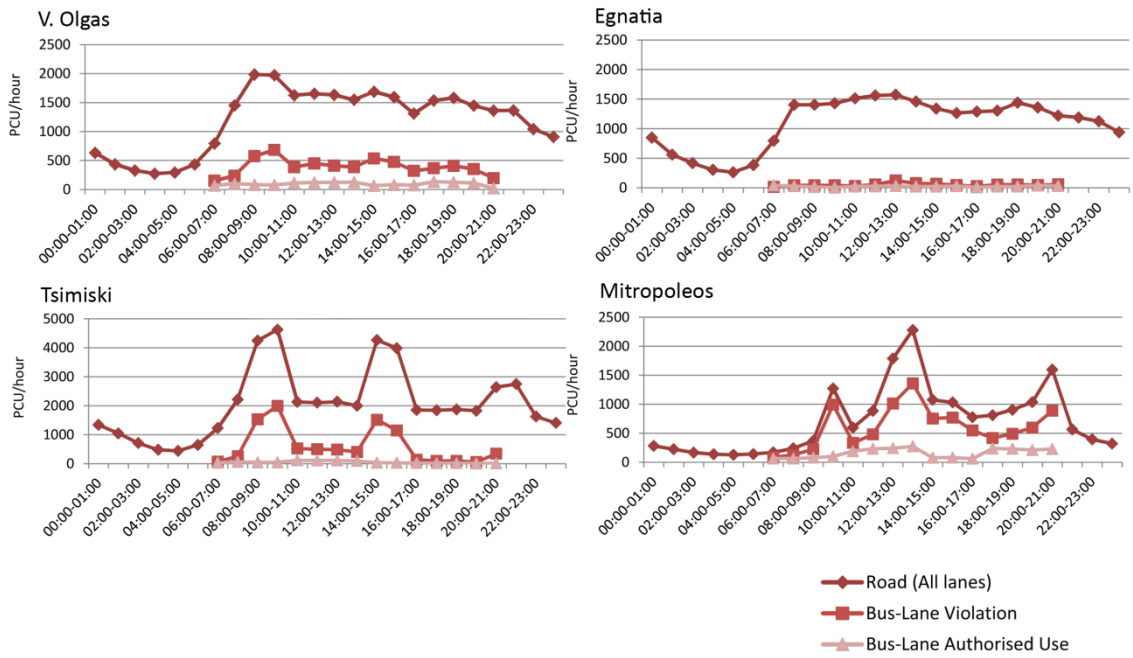

Figure 4: Hourly average traffic volume

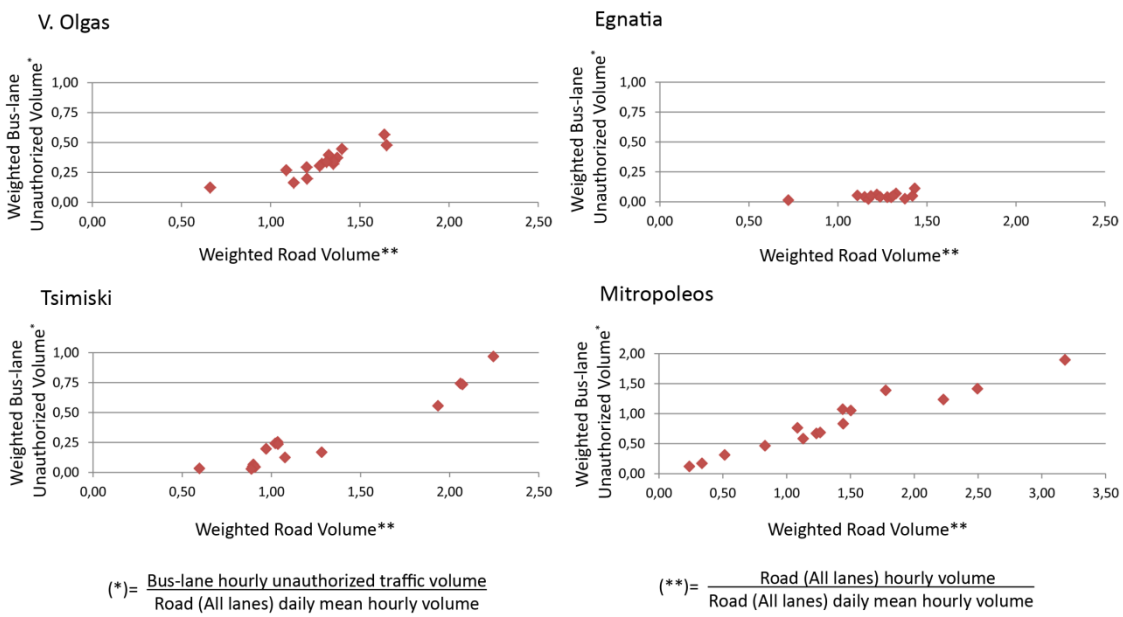

Figure 5: Weighted average hourly traffic volume

The application of indicator TRAF.2 (Daily traffic composition) in Figure 6 shows that the dominant vehicle types in the daily traffic of the road (private cars, taxis and P2W) also present the highest shares in the daily unauthorized traffic of the bus-lane. During the peak-period, the share of the unauthorized average hourly volume of P2W along the bus-lanes of the one-way main arteries V. Olgas St. and Tsimiski St. reach respectively the 83.5% and the 94.1% of the total average hourly P2W traffic of the road. It should also be pointed out that the observed similarity of the road's and the bus-lane's traffic composition for Mitropoleos St. is due to the excessive unauthorized use of the bus-lane for the reasons that were described previously.

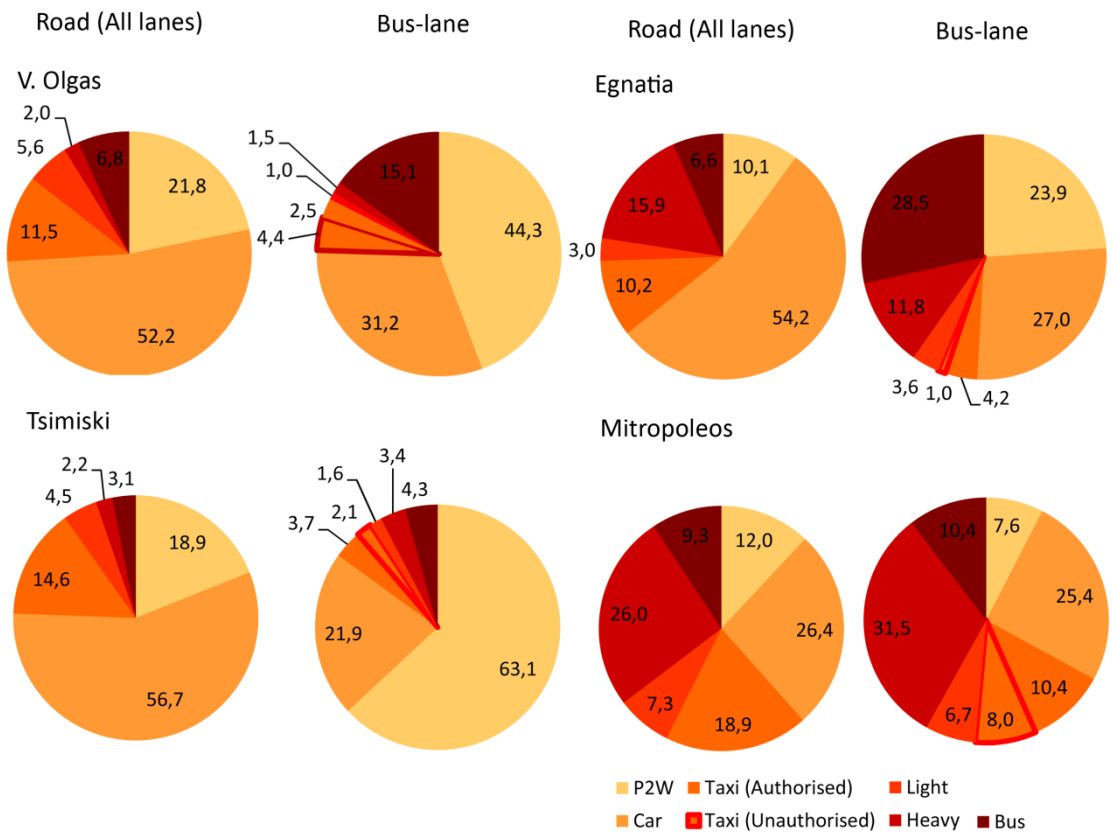

Figure 6: Daily traffic composition

As far as the results of the indicator TRAF.3 (Mean speed) are concerned, it could be concluded that there is no significant difference between the mean traffic speeds along the road and the bus-lane. In specific, the hourly average traffic speeds of both the bus-lane and the rest of the road lanes vary from 22 to 30 km/hour and from 22 to 32 km/hour during the peak and off- peak period respectively.

4.3.3 Land use indicators

In order to calculate the indicator LAND.1 (Land use intensity), the different types of adjacent land uses were recorded in a zone of influence which extends to a distance of

400 meters (walking distance) around each of the examined segments. In Table 5 there is a presentation of the share of each land use type in the total surface of the buffer zone.

Table 5: Type of land use as share of the buffer zone's surface.

	Bus-lane network			
	V. Olgas	Egnatia	Tsimiski	Mitropoleos
Land use type	% of buffer zone's surface			
Residence	82.2	39.5	34.3	32.3
Commerce	8.3	22.9	25.9	26.4
Services	0.0	1.0	2.5	2.7
Green areas	4.4	9.0	9.2	10.1
Recreation	0.0	3.4	10.9	11.2
Education	2.0	12.7	2.1	1.8
Health	0.5	1.0	0.7	0.8
Other land uses	2.7	10.4	14.3	14.8
Total	100.0	100.0	100.0	100.0

Among the above land use types, services, commerce and recreation are considered to be the main generators of bus-lane unauthorized traffic as car drivers and passengers use the bus-lanes for illegal parking or stopping in order to acquire direct access to them. In Figure 7 there is a presentation of the share of these types in the total buffer zone's surface as well as the share of unauthorized private cars on the bus-lane in relation to the road's hourly average car traffic during the peak and off-peak period.

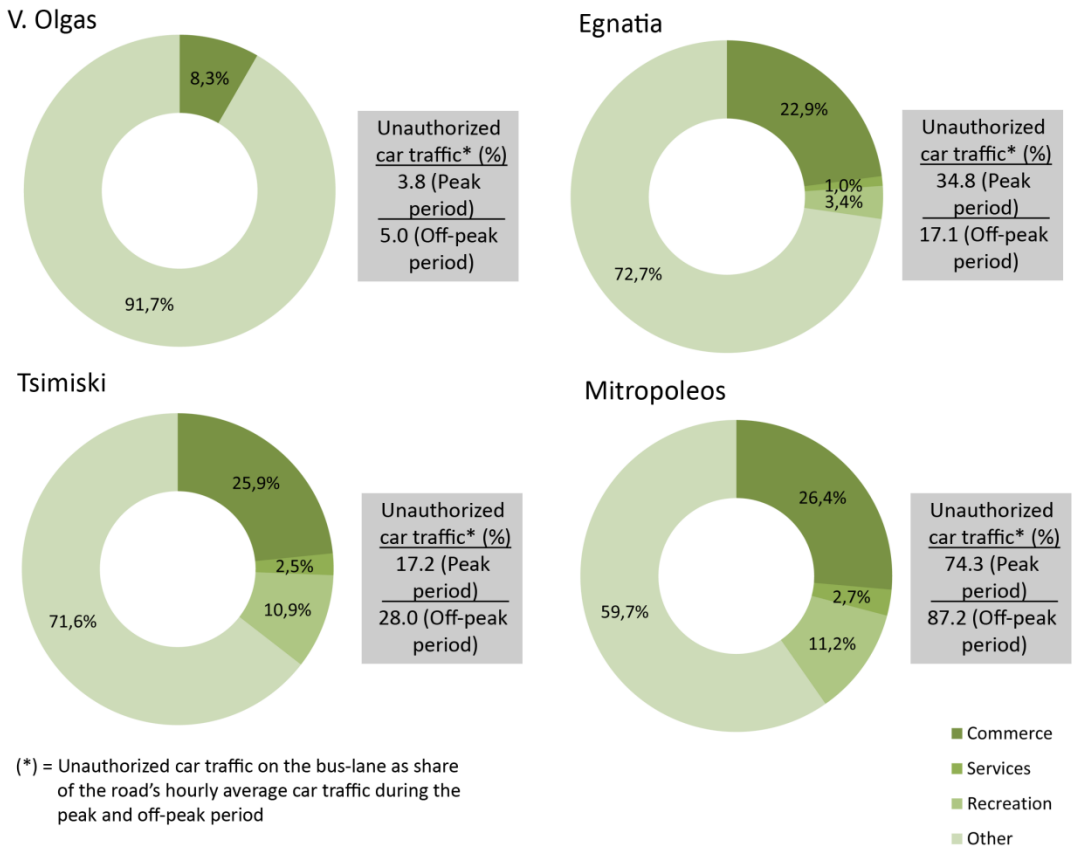

Figure 7: Share of land use surface in relation to the share of unauthorized cars in the road's hourly average car traffic

It can be observed that, despite the similarity in the intensity of commercial land uses along Egnatia St., Tsimiski St. and Mitropoleos St., there is a significant difference in the share of bus-lane violations, a fact that shows that there are other more critical local parameters that affect bus-lane violations, as the specific infrastructure features of Egnatia St. and Mitropoleos St. However, it should be pointed out that there is a great differentiation in the number of violations between peak and off-peak periods in relation to the adjacent land-use intensity, with service, commercial and recreational land uses encouraging violations during the peak period (Tsimiski St.), and residential land uses encouraging violations during the off-peak period (V. Olgas St.).

4.4 Main results from the application of the indicator system

The case study provides some interesting conclusions to the stakeholders of public transport and urban mobility in Thessaloniki especially during this period when six new bus-lanes are planned to be added to the existing bus-lane network (Municipality of Thessaloniki 2012). More specifically, these are:

- The bus-lanes along heavy traffic arteries of the CBD (main land uses: commerce, services and recreation) present higher unauthorized traffic volumes, especially during peak-periods.
- The features of road infrastructure (e.g. road narrowing, lane separation) interact with the features of bus-lane infrastructure and affect traffic violations. Thus, the

integrated design of infrastructure is essential for the discouragement of bus-lane violations.

- The hourly variation of unauthorized traffic follows a similar pattern with the road's hourly traffic variation, especially along the arteries that present distinct traffic peaks.
- The majority of bus-lane violations occur when the road's traffic volume is in the range of 100%-150% of the daily mean hourly average volume, which is below the road's capacity.
- P2W present the highest share of unauthorized traffic followed by private cars and taxis.
- Due to traffic violations, the average traffic speed along the bus-lane is similar to that of the rest of the road.

4.5 Strategic priorities

According to the above results it can be concluded that under the current conditions, the examined bus-lane network has limited effect on the improvement of the public bus system's efficiency and the discouragement of the private car use.

In order to reverse the situation, enforcement measures should be intensified for bus-lanes primarily along the arteries crossing the CBD and during the periods with relatively high traffic (when road traffic is in the range from 1 to 1.5 times the daily mean hourly average traffic). Focus should be also given on the surveillance of P2W circulation. Moreover, appropriate measures should be taken for the restriction of illegal parking especially along Mitropoleos St. As far as the bus-lane along Egnatia St. is concerned, the effect of the on-going construction of the Metro system on the operability of the bus-lane should be further examined.

Furthermore, the development of a dynamic database for the monitoring of the above mentioned features would be useful in order to be used as input to the indicator system. Thus, the proposed indicator system could be implemented: at regular intervals; before and after specific changes in the examined factors (e.g. completion and operation of the Metro system) in order to check/evaluate the performance of the existing bus-lane network, as well as during the phase of planning for new bus-lanes for the prediction of future trends in bus-lane violations.

5. Conclusions and prospects

The case study indicates that the proposed methodology can provide concrete conclusions for the impact of infrastructure, traffic and land use characteristics on the traffic violations of the bus-lane network. Moreover, the indicator system can be adapted to the requirements of each study by selecting the appropriate indicators and developing synthetic indicators for the examination of specific issues. In addition, it can be introduced into the decision making mechanism of the urban transport stakeholders combined with other methods for the evaluation of the performance of the bus-lane network and the public bus system. Finally, regarding the methodology's potential to support future research; the proposed indicators can be used as input parameters in a behavioural analysis of the drivers' attitude towards the illegal use of bus-lanes.

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Appendix 1. Technical sheets of the indicators

Thematic Field: Road infrastructure (INFR)

Code	INFR.1	**Unit**	%
Name	Bus-lane type and infrastructure		
Description	Matrix corresponding the bus-lane's specific characteristics (i.e. placement, direction, designated or type of mixed use, type of separation from traffic, prioritization or not at intersections, existence of slots for bus stops and type of traffic enforcement) with the share of unauthorized vehicles in the road's total daily traffic		
Calculation method	Estimation of the percentage of unauthorized vehicles that use the bus-lane in the road's total daily traffic by implementing the indicator TRAF.1		
Source	Own measurement and analysis of bus-lane operational and legislative framework		
Purpose	This indicator provides an assessment of how different types of bus-lanes affect the range of violations		

Code	INFR.2	**Unit**	%
Name	Road classification and infrastructure		
Description	Matrix corresponding the road's specific characteristics (i.e. classification, number of lanes, two way or one way street, type of intersections) with the share of unauthorized vehicles in the road's total daily traffic		
Calculation method	Estimation of the percentage of unauthorized vehicles that use the bus-lane in the road's total daily traffic (given by indicator TRAF.1)		
Source	Own measurement and analysis of roadway operational and legislative framework		
Purpose	The indicator provides an assessment of how different types of roadway infrastructure affect the range of bus-lane violations		

Code	INFR.3	**Unit**	-
Name	Range of road capacity		
Description	Mean hourly traffic volume of unauthorized vehicles during the scheduled period of bus-lane operation related to marginal observed values of road capacity		
Calculation method	Calculation of the marginal values (maximum and minimum) of the road segment's observed capacity during the scheduled period of bus-lane operation and related with the respective number of hourly violations (given by indicator TRAF.1)		
Source	Own measurement and analysis of roadway operational and legislative framework		
Purpose	The expression of bus-lane traffic violations in relation to the observed road capacity describes the impact of capacity restrains due to real-time traffic conditions on bus-lane traffic violations		

Thematic Field: Road traffic (TRAF)

Code	TRAF.1	**Unit**	PCU/day
Name	Daily and hourly traffic volume		PCU/hour
			%
Description	Daily and hourly-average volume of authorized and unauthorized vehicles along the bus-lane during the scheduled period of bus-lane operation, in relation to daily and hourly average volume of road traffic		
Calculation method	i. Measurement of bus-lane daily and hourly-average traffic volume for each vehicle type during the daily scheduled period of bus-lane operation		
	ii. Division of traffic volumes into authorized and unauthorized vehicles according to		

	bus-lane traffic rules iii. Measurement of road daily and hourly-average traffic volume for each vehicle type iv. Calculation of PCUs and shares (%) of the bus-lane volume in the total road volume
Source	Own measurement or extraction from traffic data sources and analysis of bus-lane operational and legislative framework
Purpose	This indicator shows: i) the overall daily volumes undertaken by the bus-lane in relation to the overall road traffic and ii) describes the hourly variation of bus-lane's authorized and unauthorized use in relation to the variation of total road traffic leading thus to the estimation of peak / off-peak flows along the bus-lane and along the road. This is also used as an input for indicators TRAF.2, INFR.3 and LAND.1

Code	TRAF.2	**Unit**	%
Name	Traffic composition		
Description	Composition of daily traffic along the bus-lane during the scheduled period of bus-lane operation, in relation to the composition of daily road traffic		
Calculation method	i. Assessment of the daily volumes (given by indicator TRAF.1) ii. Calculation of road traffic composition iii. Calculation of bus-lane traffic composition		
Source	Own measurement		
Purpose	This indicator shows the share of unauthorized vehicles by vehicle type in the bus-lane traffic as well as the composition of unauthorized traffic in relation to the overall road traffic. It also provides input for indicators INFR.1 and INFR.2		

Code	TRAF.3	**Unit**	km/hour
Name	Mean speed		
Description	Mean traffic speed along the bus-lane during the road's peak / off-peak period in the scheduled period of bus-lane operation, in relation to the corresponding peak / off-peak speed of road traffic		
Calculation method	i. Measurement of bus-lane mean traffic speed during the road's peak / off-peak period in the scheduled period of bus-lane operation ii. Measurement of road peak / off-peak mean speed		
Source	Own measurement or extraction from traffic data sources		
Purpose	The comparison of average speeds along the bus-lane and the road allows the assessment of the bus-lane's level of service during peak and off-peak periods		

Thematic Field: Land use (LAND)

Code	LAND.1	**Unit**	%
Name	Land use intensity		
Description	Matrix corresponding the adjacent to the bus-lane land use characteristics with the share of unauthorized vehicles in the total road's average hourly volume during the peak / off-peak period.		
Calculation method	Recording the intensity (as % of the total surface) of the various types of land uses adjacent to the examined bus-lane segment and related with the percentage of unauthorized traffic in the road's total traffic (given by indicator TRAF.1)		
Source	Own measurement or extraction from traffic and land use data sources and analysis of land use development framework		

Purpose	The indicator examines the relation between traffic violations with the drivers' intention to access specific land-uses