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Traffic impacts of innovative traffic and parking arrangements in Athens, Greece

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Abstract

In the city of Athens, traffic delays and high travel times are noticed due to the high levels of inner-city traffic. Consequently, sustainable mobility practices, such as enlarging sidewalks, parking management and prioritizing pedestrians and public transport are imperatively required. Within the framework of the new Sustainable Urban Mobility Plan of the city of Athens, a series of novel traffic and parking arrangements were examined, promoting public transport and active travel modes. This paper aims to assess the traffic impacts of the arrangements, examine the interventions that upgrade public space in Athens city and present an evaluation of their pilot implementation. The results indicated that, the evaluation of the pilot implementation verified the simulation model forecasts and presented significant changes in citizen habits shifting to more environmentally modes of transport.

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Keywords: Sustainable Urban Mobility; Urban Regeneration; Traffic Impacts; Traffic simulation

1. Introduction

In modern cities, both authorities and citizens are facing daily a series of options that affect urban mobility in short and long term. Several studies have highlighted the critical role of sustainable urban mobility (Banister, 2008; Pojani and Stead, 2015; Larranaga et al., 2019; Zannat et al., 2020). In particular, the transportation systems choices are several, complex and influence the city development (Tyrinopoulos & Antoniou, 2013). According to literature, restrictions on traffic capacity lead to a reduction in passenger car use. An analysis of European cities demand

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elasticities of passenger car trips from the change of travel time was conducted within the "My-TRAC" EU project. More specifically, it was found that the long-term elasticity of passenger car demand is -0.30 (De Jong & Gunn, 2001). Subsequent analysis showed that in the United Kingdom, the elasticity of passenger car demand in terms of travel time is -0.17 for car trips in urban networks on a daily basis (TAG, 2009; Wardman, 2012).

It should be noted that in different city networks, the conditions and dynamics of mode choice are different (Litman, 2010; Fearnley et al., 2017). In a study that investigates the effects of the closure of infrastructure and road sections in Oslo, it was found that the application of restrictions on road infrastructure can lead to a 13% reduction in passenger car trips (Tennøy et al., 2015; 2016). More extended management interventions, such as city tolls in London, can also lead to car trips reduced by 18% (Transport for London, 2018). Similar results have been also found for urban road use pricing in Stockholm, presenting 20% reduced traffic in 2007. Furthermore, the conversion of an existing lane to a bus dedicated lane in Trondheim (Norway) caused a slight increase in delays for the first period of intervention, while the traffic conditions were then stabilized.

Focusing on the city of Athens, the aforementioned percentages of demand reduction in terms of travel time change are quite conservative. In Athens city network, traffic delays and high travel times during peak hour are noticed, due to the high inner-city traffic. In addition, a large number of motorcycles are parked on sidewalks on the main roads of the Athens network, negatively affecting pedestrian traffic. Consequently, sustainable mobility practices, such as the enlargement of sidewalks, prioritizing pedestrians, cyclists and public transport by the existence of exclusive lanes, parking management, etc., are imperatively required.

Within the framework of the new Sustainable Urban Mobility Plan of the city of Athens, a series of novel traffic and parking arrangements for the city of Athens were examined through a macroscopic simulation analysis, with the objective of promoting public transport and active travel modes. The present study aims to assess the traffic impacts of innovative traffic and parking arrangements in the Athens city network, examine interventions that are part of a new policy of upgrading public space and present an evaluation of the predominant intervention pilot implementation.

The paper is organized as follows: in the next section, the methodology is presented, in which the simulation model and the alternative intervention scenarios are described. Afterwards, the key performance indicators on which the impact assessment was based are presented. After that, the results from the traffic simulation of the predominant scenario are discussed as well as the multi-criteria analysis results, in order for the predominant scenario to be selected. The pilot implementation evaluation then follows. In the last section of the paper, a summary of the present research results is included, while the key findings, proposals for further research and paper limitations are also presented.

2. Methodology

2.1. Study area

In the present study, the examination of alternative traffic management schemes was performed through a macroscopic simulation analysis using the NTUA traffic simulation model for Athens in the Aimsun mobility software, which is presented in Fig. 1 (a). In addition, the traffic impact assessment was evaluated in relation to two areas of analysis shown in Fig. 1 (b), the Intervention Area and also the Wider Analysis Area, which is considered to be affected more by the proposed interventions.

Focusing on the network geometry, the simulated network consists of 1,137 nodes and 2,580 sections. In addition, the total length of road sections is 348 km and the network size reaches approximately 20 km^2. In the simulated model geometric and functional characteristics of each section were included (length, width, number of lanes, directions, free flow speed and capacity) as well as the respective characteristics of each node (allowed movements, number of lanes per movement, priority, traffic light control plans, traffic signs, free flow speed and capacity).

The simulated model also included data collected in 2019 from 107 detectors of main roads in the city of Athens and additional data from field measurements that carried out in 2019 at selected nodes of the study area. According to these data, it was found that the morning peak hour is 08:00-09:00 which corresponds to 6.2% of the daily traffic. In addition, the origin-destination (OD) matrices of the study network consisted of 292×292 centroids and a total number of 82,270 car trips and 3,110 truck trips for the morning peak hour (08:00-09:00). Furthermore, 95 bus, 14 trolley lines and 1,030 public transport stations were included in the simulated network, as well as their frequencies and waiting times at stops. Finally, a verification procedure of extracted travel times was conducted for model validation, by comparing travel times obtained using the GoogleMapsAPI application for specific routes within the study area.

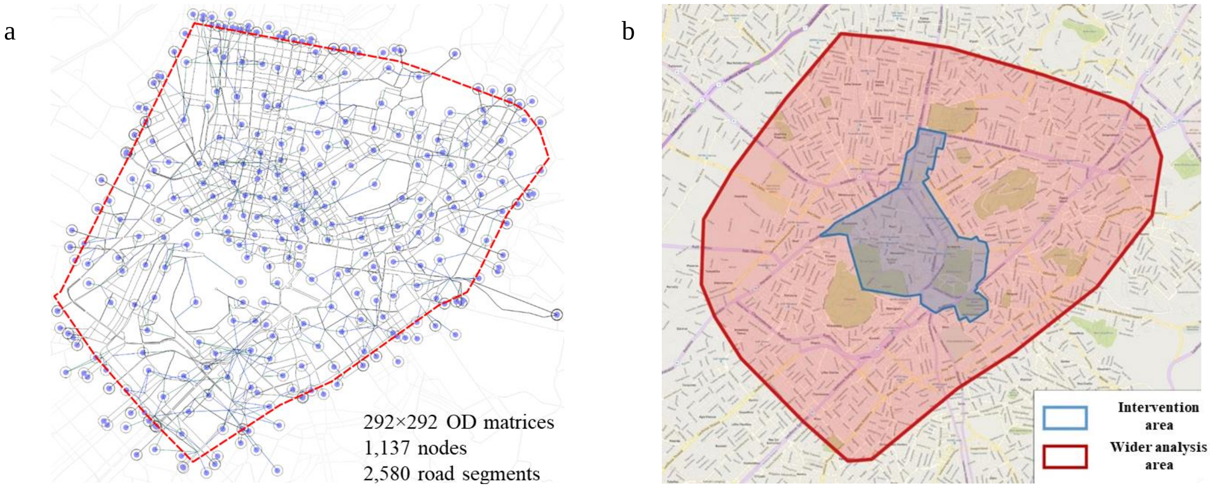

Fig. 1. (a) Athens network in Aimsun software; (b) the analysis areas.

2.2. Simulated scenarios

In the context of upgrading sustainable urban mobility in the city of Athens, a series of alternative scenarios were tested. More specifically, the simulated scenarios were the current conditions (scenario A) as well as four alternative scenarios (scenario B1, B3, C1, C0) that included interventions related to:

- Enlargement of sidewalks in several streets
- Adding new exclusive lanes for pedestrians, cyclists and public transport
- Parking management
- Traffic arrangements at Commercial Triangle and Plaka district
- Setting 30 km/h speed limit.

The alternative scenarios mainly differed in the traffic conditions of Panepistimiou street, which was considered as the reference area. In current conditions, Panepistimiou is a six-lane street (five traffic lanes and one contraflow bus lane) with a total length of 1.1 km. The alternative scenarios comprised an increase of sidewalks in Panepistimiou street by decreasing traffic lanes and removing the contraflow lane. More specifically, scenario B2 simulated Panepistimiou street as a three-lane street (two traffic lanes and one parallel bus lane), scenario B3 as a four-lane street (three traffic lanes and one parallel bus lane), scenario C1 as two-lane street (one traffic lane and one parallel bus lane) and C0 as a pedestrianized street (free of private vehicles). These interventions as well as more minor ones of each alternative scenario are summarized in Table 1.

Moreover, two additional scenarios (scenarios B2 and B4) were investigated, concerning the modal shift from passenger cars to public transport in the corresponding scenarios B1 and B3. Based on findings of the study conducted by Koliou et al. (2019), the modal shift from passenger cars to public transport was estimated and it was found that the total reduction of the passenger car travel demand was approximately 9% and 8% for scenario B2 and B4 respectively. The proposed interventions of scenarios B1 and B3 aim to eliminate the use of private cars, for both trips with origin and destination from and to the city center, and for intercity traffic as well. It is therefore clear that an increase in travel times on some specific road sections of the network or on entire routes in the study area will be observed, leading to a user behavior change regarding mode choice. Thus, this will be investigated by the B2 and B4 scenarios implementation that take into account the mode shift.

Table 1. Alternative intervention scenarios.

		B1	B3	C1	C0
Panepistimiou Str.:	increase of sidewalk (2 traffic lanes for all vehicles & 1 new parallel flow bus lane & removal of contraflow bus lane)	✓			
	increase of sidewalk (3 traffic lanes for all vehicles & 1 new parallel flow bus lane & removal of contraflow bus lane)		✓		
	increase of sidewalk (1 traffic lanes for all vehicles & 1 new parallel flow bus lane & removal of contraflow bus lane)			✓	
	free of private vehicles				✓
Akadimias Str.: traffic flow reversal & 1 new parallel flow bus lane					✓
Syntagma Sq.: increase of sidewalk (3 traffic lanes for all vehicles & 1 new bus lane)		✓	✓	✓	✓
K. Palama, Aigyptou Sq., Averof, Aischinou, Frinihou, Agras, Artemidos Str.: free of private vehicles		✓	✓	✓	✓
Olgas Av.: free of private vehicles		✓	✓	✓	✓
Amalias Av.: increase of sidewalk (2 traffic lanes for all vehicles & 1 new bus lane)		✓	✓		✓
Athinas, Ermou, Mitropoleos, Aiolou Str.: free of private vehicles		✓	✓	✓	✓
Perikleous, Kolokotroni, Lekka Str.: free of private vehicles				✓	
M. Avriliou, Kriezotou, Tositsa, Monastiriou, Timaiou Str.: increase of sidewalk		✓	✓		✓
I. Attikou, R. Feraiou, Othonos Str.: free of private vehicles		✓	✓	✓	✓
Commercial Triangle and Plaka district: free of private vehicles		✓	✓		✓
Filellinon Str., Akadimias Str., Sofias Av.: 1 new bus lane		✓	✓	✓	✓
A. Sygrou Str.: 1 new bus lane		✓			✓
30 km/h speed limit in intervention area		✓	✓		✓
Parking arrangements		✓	✓	✓	✓
Optimization of traffic signal programs		✓	✓	✓	✓

2.3. Key Performance Indicators

The impact assessment was based on the calculation of the following six Key Performance Indicators (KPIs) related to passenger car traffic, public transport, bicycles and pedestrians.

- KP1 1: Average speed, vehicle-hours for private cars within the intervention area
- KP1 2: Level of service within the intervention area and the wider analysis area
- KP1 3: Travel times on selected road axes within the intervention area
- KP1 4: Urban reforms on road axes and streets with limited access to passenger cars
- KP1 5: Bus lanes length
- KP1 6: Average public transport speed on selected road axes of the intervention area

The first KPI (KPI 1) considered vehicle-kilometers and vehicle-hours calculations based on Equations 1 and 2, respectively.

$$\text{vehicle-kilometres} = \sum_{l=1}^{L}\sum_{m}^{M} V_{l,m}\cdot\alpha_m\cdot Len_l + \sum_{t=1}^{T}\sum_{m}^{M} V_{t,m}\cdot\alpha_m\cdot Len_t \quad (1)$$

$$\text{vehicle-hours} = \sum_{l=1}^{L}\sum_{m}^{M} V_{l,m}\cdot\alpha_m\cdot T_{l,m} + \sum_{t=1}^{T}\sum_{m}^{M} V_{t,m}\cdot\alpha_m\cdot T_{t,m} \quad (2)$$

where $V_{l,m}$: is the estimated traffic volume of each vehicle type *m* (private cars, heavy vehicles and public transport) for each lane of each section *l*, $V_{t,m}$: is the estimated traffic volume of each vehicle type *m* (private cars, heavy vehicles and public transport) for each turn of each node *t*, α_m: is the Passenger Car Unit (PCU) factor, Len_l and Len_t: is the length of each lane *l* and turn *t* respectively in kilometers, $T_{l,m}$ και $T_{t,m}$: is the estimated travel time of each vehicle type *m* (private cars, heavy vehicles and public transport) for each lane of each section *l* and for each turn of each node *t* in hours.

In addition, the average speed of vehicles was calculated based on Equation 3.

$$average\ speed = vehicle\text{-}kilometres / vehicle\text{-}hours \tag{3}$$

Regarding the second KPI (KPI 2), the ratio of traffic volume to road capacity and a service level analysis was conducted (based on HCM2000), by using the data extracted from traffic simulation for traffic representative road sections in the wider analysis area and in the intervention area as well.

The third KPI (KPI 3) was estimated for selected road segments, representative of the traffic in the wider analysis area, but also in the intervention area. More specifically, the average travel time and the ratio of the average speed to the free flow speed were calculated, taking into account at a macroscopic level the vehicle movements in sections as well as in nodes (turn movements). Using the ratio of the average speed to the free flow speed and the level of service categories by HCM2010, the service level of the selected axes was characterized.

In addition, the fourth KPI (KPI 4) considers the intervention areas (in m^2) proposed in each alternative scenario using approximate data from satellite images. More specifically, the proposed sidewalks and the restricted traffic lanes were taken into account.

For the fifth KPI (KPI 5) estimation, data were obtained from the OASA telematics for the current condition of the exclusive bus lanes in the wider analysis area and in the intervention area, a comparison of the length (in meters) of the exclusive use public transport lanes in the current condition and in the alternative scenarios, as they are formulated. Finally, in the present study, the average speed of the exclusive bus lanes along Panepistimiou street and Akadimias street was examined (KPI 6). More specifically, the average speed of the lines passing either along their entire length or in individual sections was estimated according to Equation 4. The average speed estimation was performed using microscopic simulation.

$$Average\ public\ transport\ speed\ = \sum_{i}^{I} u_i \cdot Len_i \Big/ \sum_{i}^{I} Len_i \tag{4}$$

where u_i: is the average speed (km/h) of each bus line i and Len_i: is the bus line length.

3. Results and discussion

Examining simulation results (Table 2), it is observed that the examined interventions do not significantly affect the performance of the wider analysis area, while on the contrary some changes in traffic conditions in the intervention area are noticed. Moreover, the implementation of the intervention seems to affect only passenger cars traffic and more specifically a low percentage of trips that take place inside the city of Athens. In addition, the implementation of the proposed interventions resulted in a significant improvement in the mobility conditions of pedestrians and non-motorized vehicles. Traffic conditions of public transport are significantly improved through the priority measures of their movement that were considered in the alternative scenarios. Furthermore, the optimization of traffic signal programs seems to also improve traffic conditions by eliminating high delays in peak hours and by prioritizing public transport operations. In addition, signal optimization can provide a higher level of service to private vehicles users by selecting alternative routes except for passing through the city center, reducing congestion, pollution, and increasing accessibility to the city center.

Comparing the alternative intervention scenarios results extracted from the simulation (Table 2), no major differences were noticed, while the choice of the B1/B2 scenario over the rest of the scenarios seems to pave the way for the implementation of a new sustainable urban mobility plan. More specifically, scenario B1/B2 offers accessibility to pedestrians and cyclists improves public transport operation and reduces passenger cars. Overall, scenario B1/B2 provides a significantly upgraded quality to urban mobility compared to the current conditions by offering more comfortable, safer and green trips.

Finally, the traffic impact indicators of the simulation analysis provided that the proposed interventions lead to significant benefits in mobility in the city of Athens, which will make the city of Athens even more attractive. In addition, the proposed traffic regulations led to a reduction in average speed improving road safety and developing a new culture for safer behaviour of all road users.

Table 2. Impact assessment for alternative scenarios.

		B1	B2	B3	B4	C1	C0
KPI 1	Vehicle-hours for private cars (intervention area)	+7.2%	-22.6%	+4.3%	-22.5%	+24.5%	+6.7%
	Average vehicle speed (intervention area)	-18.1%	-3.1%	-13.5%	-0.4%	-28.3%	-16.5%
KPI 2	Level of service (intervention area)	+7.8%	+4.2%	+6.7%	-5.5%	+13.6%	+3.6%
	Level of service (wider analysis area)	+1.8%	-3.7%	+1.1%	-3.6%	+4.4%	+2.3%
KPI 3	Travel times (intervention area)	+18.1%	+3.1%	+13.5%	+0.4%	+28.3%	+16.5%
KPI 4	Urban reforms on road axes	+10ha	+10ha	+9ha	+9ha	+10ha	+6ha
	Streets with limited access to passenger cars	+5ha	+5ha	+5ha	+5ha	+5ha	+4ha
KPI 5	Bus lanes length (affecting 50 bus lines)	+3.8km	+3.8km	+2.6km	+2.6km	+2.1km	+2.1km
KPI 6	Average public transport speed (Panepistimiou Str.)	+28%	+35%	+32%	+37%	-7.2%	+28%
	Average public transport speed (Akadimias Str.)	+22%	+26%	+23%	+27%	-	+22%

Taking into account the above results, the predominant scenario was found by using multi-criteria analysis (Dodgson et al., 2009). According to the Analytical Hierarchy Process method results (Table 3), scenario B1/B2 was evaluated 32% higher than the current conditions, while scenario B3/B4 was 30%, scenario C0 was 24% and scenario C1 was 22%. Therefore, scenarios B1/B2 showed slightly lower performance in motorized travel-related indicators, while presenting overall the optimal performance among the alternative intervention scenarios.

Table 3. Alternative intervention scenarios performance.

		B1/B2	B3/B4	C1	C0
KPI 1	Vehicle-hours for private cars (intervention area)	3,3%	3,4%	2,8%	3,3%
	Average vehicle speed (intervention area)	2,3%	2,4%	2,0%	2,4%
KPI 2	Level of service (intervention area)	2,0%	2,1%	1,9%	2,1%
	Level of service (wider analysis area)	1,7%	1,7%	1,7%	1,7%
KPI 3	Travel times (intervention area)	6,5%	6,6%	6,0%	6,6%
KPI 4	Urban reforms on road axes	5,2%	5,1%	5,0%	5,2%
	Streets with limited access to passenger cars	49,8%	48,4%	51,3%	42,2%
KPI 5	Bus lanes length (affecting 50 bus lines)	23,0%	23,0%	23,0%	21,6%
KPI 6	Average public transport speed (Panepistimiou Str.)	18,5%	17,7%	15,1%	16,8%
	Average public transport speed (Akadimias str.)	19,8%	20,1%	14,7%	19,8%
Total performance		**132%**	130%	124%	122%

Subsequently, the predominant scenario, namely scenario B1, was implemented in the city of Athens. Hence, a series of vehicle and pedestrian traffic real data were collected for both periods before and after the pilot implementation as shown in Fig. 2. The measurements were compared for the period before the implementation of the regulations (12/6/2020) and a period of pilot implementation (13/7-17/7/2020). Google Maps (GoogleMapsAPIs) were used to extract and record the daily traffic data and in particular travel time measures. In particular, data on private vehicle travel times, traffic volumes and modal split were analyzed.

a b

Fig. 2. (a) Before and (b) after pilot implementation in Panepistimiou Str.

In order to verify the forecasts of the simulation model, a comparison was made between the observed travel times of the pilot implementation and the predicted ones. The results of the comparisons are presented in Table 4 and show that the observed traffic conditions confirm the forecasts of the simulation model for the majority of road segments. A small exception is Amalias Av. (from A. Diakou to Panepistimiou Str.) where the simulation model predicted a difference of 0.1 minutes while the difference in travel time after pilot implementation compared to before was 1.5 minutes higher.

Table 4. Travel time (minutes) comparison of simulation forecasts with pilot implementation real data.

	Traffic simulation forecast			Pilot implementation real data			Difference
	A	B1	Diferrence	Before	After	Diferrence	
Main roads							
Panepistimiou Str.	2.9	5.1	2.2	2.7	3.8	1.1	-1.1
Akadimias Str.	4.9	4.9	0.0	4.9	4.2	-0.7	-0.7
Solonos Str.	4.4	5.1	0.7	7.1	6.9	-0.2	-0.9
Stadiou Str.	3.3	3.7	0.4	2.7	2.3	-0.4	-0.8
Entry roads							
Sofias Av. (ftom Konstantinou Av. to Panepistimiou Str.)	3.4	3.1	-0.4	4.6	4.2	-0.3	0.1
Sofias Av. (ftom Kifisias to Konstantinou Av.)	5.5	5.0	-0.5	4.3	4.2	-0.1	0.5
Amalias Av. (from A. Diakou to Panepistimiou Str.)	1.9	2.0	0.1	3.6	5.3	1.6	1.5
Patision Str.	2.7	2.6	-0.1	3.0	3.0	0.0	0.1
Exit roads							
Sofias Av. (ftom A. Diakou Str. to Sofias Av.)	4.4	4.9	0.5	5.2	4.1	-1.1	-1.6
Sofias Av. (ftom Sofias Av. to A. Diakou Str.)	4.4	4.3	-0.1	5.7	4.9	-0.8	-0.7
Amalias Av.	1.6	2.2	0.6	1.3	1.3	0.0	-0.6
Filellinon Str.	1.8	3.2	1.5	1.3	1.2	-0.1	-1.6
Ring roads							
Konstantinou Av.	2.0	1.9	-0.1	6.7	6.2	-0.5	-0.4
	3.8	3.9	0.0	5.6	4.3	-1.3	-1.4
Alexandras Av.	9.0	9.6	0.5	7.8	9.0	1.1	0.6
	7.1	7.2	0.1	7.8	9.0	0.5	0.4

4. Conclusion and future works

The objective of the present study is the development and investigation of traffic and parking regulations in the city of Athens aiming to upgrade public space, and present the impacts of the proposed interventions on urban mobility. The traffic impact assessment was evaluated in regards to two analysis areas namely, the intervention area and the wider analysis area. In order to assess the traffic impacts, a traffic simulation was performed and the most critical indicators related to the transport system operation under current conditions were defined. In the context of upgrading sustainable urban mobility in the city of Athens, a series of alternative scenarios were tested. More specifically, the simulated scenarios were the current conditions as well as four alternative scenarios. Moreover, two additional scenarios were also investigated, concerning the modal shift from passenger cars to public transport. In addition, the alternative intervention scenarios were compared with the current situation using the Analytical Hierarchy Process (AHP) and the predominant scenario was selected and its pilot implementation was evaluated.

According to traffic simulation results, it is observed that the examined interventions did not significantly affect traffic conditions of the wider analysis area, while on the contrary slightly affected the conditions of the intervention area. In addition, the implementation of these interventions impacts considered only passenger cars traffic. Moreover, a significant improvement in the pedestrians and non-motorized vehicles mobility conditions was provided by the implementation of the examined interventions. Traffic condition of public transport vehicles was also significantly improved by eliminating high delays in peak hours and prioritizing their operation.

Overall, the proposed interventions in the mobility of the city of Athens lead to significant benefits. More specifically, the selected interventions achieve a significant improvement of public space by concerning Commercial Triangle and Plaka district free of private vehicles, as well as introducing new and sustainable mobility practices prioritizing public transport vehicles and offering safer and more comfortable pedestrians and bicycles traffic.

The evaluation of the pilot implementation proved that the interventions led to decreased use of private cars. The traffic and parking arrangements improved the level of service for the existing public transport and increased the amount of travel for active modes. Finally, the pilot implementation verified the forecasts made by the simulation model and showed that the new traffic and parking interventions were implemented by a relatively fast adaptation. Therefore, the present study illustrates that sustainable urban mobility practices made significant changes in citizens' habits by shifting to more environmentally modes of transport.

The encouraging results of the present research could provide an opportunity for the expansion of the new policy of sustainable urban mobility in all areas of the municipality of Athens, aiming for a gradual implementation of an integrated network of bicycle lanes. In addition, the paper outcomes could enable policy makers and stakeholders to promote more sustainable urban transport, and road users to select more environmental transport modes in order to address urban environmental and transport-related problems. The currently provided framework will be beneficial for future management of cities, as sustainable urban mobility management is complex and requires suitable innovative strategies. Finally, it is to note that the present study entails some limitations and several pending issues remain open for future research to examine. Various impacts in relation to other or the examined traffic and parking arrangements need to be further investigated, taking into account the particularities of different urban networks, modes of transport and modal split issues. In addition, it is envisioned that a microscopic or a partially (hybrid) traffic simulation approach could be used in order for direct impacts (trip-by-trip basis) to be estimated.

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