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Evaluation of a High Occupancy Vehicle Lane in Central Business District Thessaloniki

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Abstract

Travel Demand Management (TDM) measures, whose primary objective is to alleviate the impacts of traffic and congestion in the urban environment, are nowadays increasingly used to address complex transportation and mobility puzzles. One of the most representative TDM measures is the High Occupancy Vehicles (HOV) lane. This paper presents and discusses the results of the hypothetical implementation of an HOV lane in the CBD area of Thessaloniki, Greece. The impact evaluation was conducted through traffic simulation modeling techniques and the results are expressed in terms of environmental and traffic indicators. The environmental and energy aspects of the examined HOV lane are the focus of attention of the current study, in an effort to assess their contribution to rising sustainability issues. The HOV lane in Thessaloniki's case study proved to be, in principal, an efficient tool for managing transport demand. Nevertheless, there is a need for further examination of the impacts on the whole network.

Keywords: travel demand management (TDM); high occupancy vehicles (HOV) lanes; transport modelling; environmental impacts.

1. Introduction

More often than not, rising transportation and mobility issues worldwide are confronted with the realization of infrastructure projects aiming to deal with a limited number of problems at a time; a more holistic approach to these problems would barely include the terms of construction and implementation. On the contrary, it would circumvent the need and focus for additional infrastructure, while at the same time providing solutions to rising parallel issues, such as road safety, land use and environmental protection, as Newman and Kenworthy suggest (Newman & Kenworthy, 1999). The introduction of measures that manage travel demand, rather than serve or directly respond to it, can enhance the diversity and efficiency of existing transportation systems.

Aiming at increasing the average number of passengers per vehicle, reducing traffic congestion and lowering the levels of pollutant emissions in determined lanes (Bonsall, 1981), HOV lanes are one of the most representative travel demand management measures (TDM). Under the TDM terminology, falls a wide set of concepts and actions

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aiming at influencing people's travel behavior in such a way, that alternative mobility options are encouraged and/or traffic congestion is alleviated (Meyer, 1999). TDM "refers to various strategies that change travel behavior (how, when and where people travel) in order to increase transport system efficiency and achieve specific objectives such as reduced traffic congestion, road and parking cost savings, increased safety, improve mobility for non-drivers, energy conservation and pollution emission reductions" (VTP, 2010). In compliance with TDM objectives, HOV lanes encourage the collective use of cars, by allowing the use of exclusive lanes to vehicles occupied by a specified minimum number of passengers (Golob et al., 1989). Depending on the application, two, three or four occupants' vehicles, indicated as 2+, 3+, or 4+, are granted access in the HOV lane. In this way, the transportation of more people in fewer vehicles is promoted, adding to the improvement of the traffic conditions in the lane of implementation (Pratt et al., 2000).

HOV lanes, however, have also been addressed with criticism over time. Dahlgren purports that adding an HOV lane is only then more effective in reducing overall congestion than adding a mixed flow lane, when significant delay remains on the mixed flow lanes after the introduction of the HOV lane (Dahlgren, 1998). In an effort to manage troubling phenomena associated with the existence of HOV lanes, such as the "empty-lane syndrome" (when HOV lanes are under-utilized), authorities are discussing the replacement of existing HOV lanes with "managed lanes"; lanes that will provide access for express trips, buses, commercial vehicles, zero emission vehicles, energy efficiency vehicles, tolled vehicles besides the high occupancy vehicles (FHA, 2002). Kwon at al. suggest this fact could be seen as an indirect admission of the failure of HOV facilities to live up to the expectations, while others argue this is an evolution of stages in their life cycle (Kwon, 2008 & Swisher et al., 2002). Giuliano at al. formulated a fundamental question accompanying every HOV lane project; do HOV lanes attract new carpoolers and increase person throughput overall, or do they simply divert existing carpoolers and transit users from general purpose lanes (Giuliano et al., 1990)?

Interest in carpooling sparkled in the early '70s in response to the fuel shortage issues arising after the OPEC (Organization of Petroleum Exporting Countries) embargo (Noland et al., 2001). The U.S. has since been the most active advocate of HOV schemes, with HOV lanes being in operation in nearly 12 countries around the world currently. The first HOV operation dates back to 1969 and was implemented in San Francisco, California, providing priority to HOV 3+, while the first European attempt is that of the city of Leeds, UK in 1998. Schijns' at al. international research in 2006 found that "there are over 4,000 HOV lane km in use, spread among approximately 80 arterial projects and over 130 motorway applications" worldwide (Schinjs, 2006).

Within the framework of this paper, the traffic, environmental and energy impacts of the implementation of an HOV lane are outlined, with the city of Thessaloniki, Greece acting as the reference area. Thessaloniki is the second largest city in Greece, currently accommodating approximately 1,104,000 citizens in its greater area according to the 2011 census. It is situated in Northern Greece, covering a land area of 138,847 km2 with its geographical location playing a significant financial and commercial role within the domestic and greater Balkan region (General Secretariat, 2007). Thessaloniki has experienced many different population levels, partly through absorbing and engulfing neighbor suburbs and villages into its greater metropolitan region. As the city grew in size, the original monocentric structure of a large metropolis reserved its form, with 25% out of 1,600,000 daily trips in 1998 having their end in the central district area (Denco et al., 1999). The Thessaloniki General Transportation Study (TGTS) states that a total of 30,5% of those trips were conducted by private cars (as a driver) while the respective percentage of trips made by passengers in private cars was found to be 10,1%. Despite its population size and growth, the city serves as an exemption on a European level; it still remains without a public transport system of fixed route. This reason accounts for the considerably low share of Public Transport, that being close to 27,5%, while the respective figure for the city of Athens is found to be 43%, due to the extensive Public Transport network deploying metro, tram, bus, trolley bus, electric railway and suburban train systems (AUTO, 2004). Thessaloniki's severe transportation and traffic related environmental problems are usually tackled with the implementation of large-scale infrastructure projects that are either currently under construction (i.e. metro) or under consideration (i.e. outer ring road, submerged tunnel to bypass the city centre). TDM measures on the other hand have rarely been at the crux of the transportation agenda, even if the last major home based questionnaire survey in the city showed the opposite; a total of 73% of the people participating in the survey gave an approbatory answer on the introduction of car-pooling measures in Thessaloniki. Despite this fact, any efforts towards the implementation of an HOV lane still remain on a research level.

2. Experimental Section

Figure 1 shows the links of the central road network of the city, where the HOV lane was planned for implementation. The specific road axis consists of three streets and is located in the CBD area of the city. The road axis extends to a total of 1.6 km and serves lower traffic volumes compared to adjacent streets due to its poor geometrical characteristics; (one way street with one lane along Svolou Street and Keramopoulou Street (westbound direction) and one lane per direction along Ermou Street for all types of vehicles). However, its role to the central network function is of great significance, since it is one of the three central axes that provide connection of the eastern part with the western part of the city through the city centre. These streets and their interconnections form the buffer zone. The allowed entrance points to the HOV lane are also outlined in Figure 1 in red bullets (points A and B), whereas the end of the HOV lane is at point C. The idea behind the choice of number (two) and location of the entrance points was in accordance with the main objective of the measure, that being the reduction of delays. A greater number of allowed entrance points to the lane would on the one hand enhance accessibility, but would at the same time disturb the otherwise uninterrupted traffic flow of the HOV lane. The first entrance point was placed in the eastern end of the proposed HOV lane, to signify its beginning. The length of the HOV corridor would not justify the placement of denser entrance points; therefore the second and last one was located in the middle of the corridor. Both entrance points were situated in the nodes that service the highest traffic flow along the corridor. All turning movements towards the HOV lane have been prohibited, while all turning movements from the lane have been preserved as they currently are (the majority of the turning movements are regulated with traffic lights and two-way stops). These changes were applied to vehicles of all classes, but that of buses, whose prescheduled route remained the same.

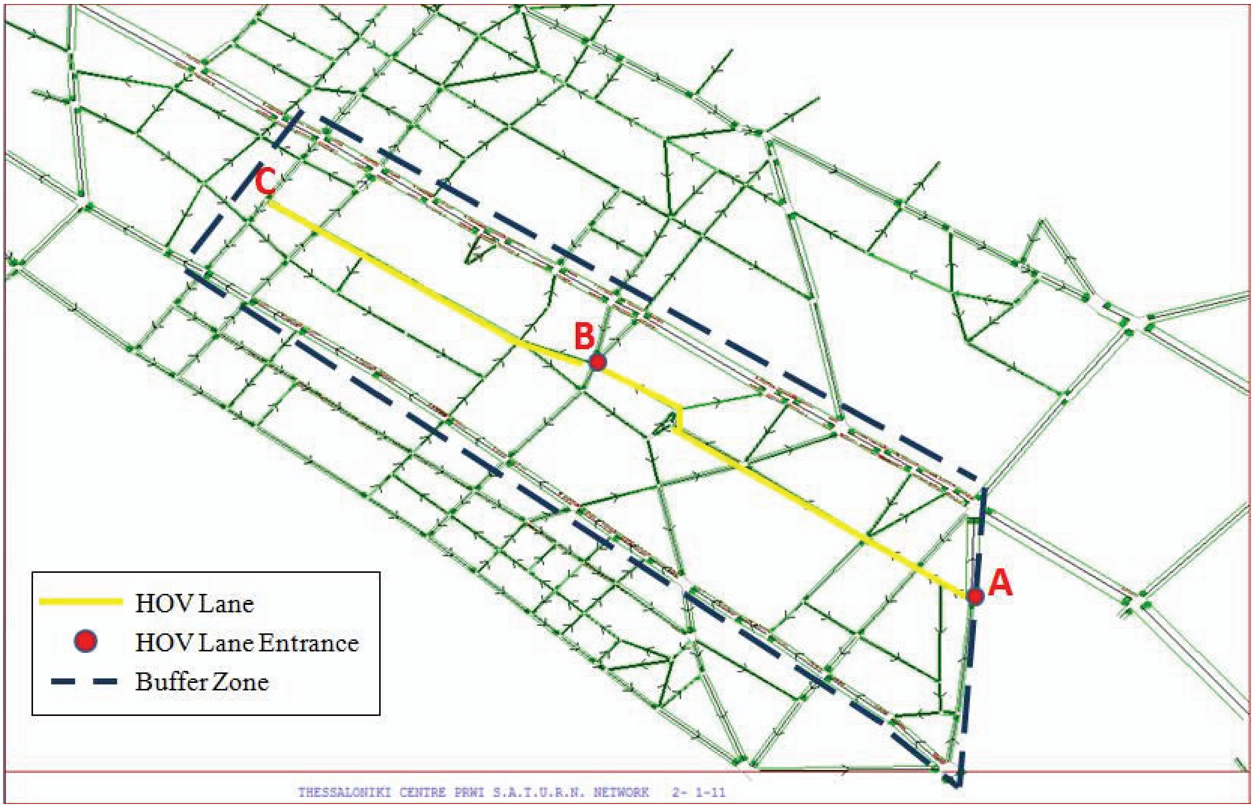

Figure 1. Graphic representation of the central area tested in SATURN

Since the reference area of implementation is largely characterized by residential and commercial land use, the allowed classes of vehicles entering the lane were adjusted to the existing conditions. Besides vehicles carrying two or more passengers (2+, including taxis), motorcycles, public and state cars, and buses, two extra categories including vehicles of residents of the street (independent of occupancy) and goods' vehicles, were also considered to be allowed to enter the lane.

Data and facts presented in this study derive from a research conducted by the Faculty of Rural & Surveying Engineering of the Aristotle University of Thessaloniki in 2007 (Kitis et al. 2007), concerning the implementation of an HOV lane in the centre of Thessaloniki. The results in section 4 are based on the examination of the following scenarios: Scenario 1 ("Before" situation): The road axis, as shown in Figure 1, from Aggelaki Street/eastern part of the city (point A) along Svolou Street, Keramopoulou Street and Ermou Street (point B) to Dragoumi Street/western part of the city (point C), without an HOV lane (as the situation currently stands: one lane for all types of vehicles, parking allowed at both sides of the streets). Scenario 2 ("After" situation): The road axis of implementation with an HOV lane (running only throughout morning - 07:00-09:00 - peak hours), the entrance to which is limited in two points (A and B) and to which all turning movements are prohibited.

What concerns the traffic volume applied to the lane in the "After" scenario that was deducted from the following information: (a) the number of residents' vehicles entering the lane, either without any other passenger (Single Occupancy Vehicle - SOV)or with at least one more passenger in the vehicle (High Occupancy Vehicle - HOV) (b) the number of vehicles that are currently classified as HOV (c) the number of vehicles that will be classified as HOV after the implementation of the measure. In an effort to accurately estimate these figures, a set of actions were undertaken since data was not directly available. For (a), the average national private car occupancy was found to be 405 vehicles per 1,000 residents, while the respective number of residents was found to be 5,000 for the road axis of implementation. Calibration measures were made for the calculation of (b), where 60% of the vehicles currently travelling through the proposed road axis, were found to fulfill the HOV requirements of the lane (2+). The calibration measures included field research in the proposed entrance points of the HOV lane, in three different weekdays (16th to 18th May 2007) during the morning peak hours (8:00am - 9:30am). The observers had to fill in a research sheet identifying the number of passengers in every vehicle. Finally, an assumption concerning the percentage of people changing from SOV to HOV after the introduction of the HOV lane was made for (c), with that percentage concluded to be 5%. However, a more detailed sensitivity analysis on this specific parameter could determine this percentage in a more scientific detail.

3. Simulation Model

The traffic simulation model that was used for the evaluation of the scenarios concerning the implementation of an HOV lane in the city of Thessaloniki was SATURN (Simulation and Assignment of Traffic to Urban Road Networks) (Van Vliet, 1982). SATURN is a suite of flexible macroscopic network analysis programs, developed at the Institute for Transport Studies, University of Leeds, UK. It is a combined traffic simulation and assignment model at a macroscopic level for the analysis of traffic management schemes over relatively localized network. The use of SATURN as a tool to assess traffic and environmental impacts has been proved of great importance in various research efforts in the city of Thessaloniki. The SATURN extended road network used for the purposes of this paper consists of 245 simulation nodes and 43 zones, and includes the whole Thessaloniki's central area (Figure 1). The respective nodes include 113 priority junctions, 84 traffic signals, 31 external nodes, 16 dummy nodes and 1 roundabout.

The Thessaloniki SATURN model was developed, calibrated and validated in 2003 representing the average traffic flows and congestion conditions during the morning peak period in the city center. The overall average speed of the network is 7.7 km/h (including junction delays) and the average trip distance in the model is 1.82 km (the distance's values represents the range of the modeled area, i.e. only the CBD of the city is modeled). The data used for the development of the model derive from Thessaloniki's General Transportation Study. To the writing of this report, no official validation of the data had been possible. The values of the performance indicators were calculated for the road network "before" and "after" the implementation of the proposed HOV lane. The parameters examined in this research include traffic volumes, speed, delays, and the use of the road network expressed in travel distance (pcu*km) and in travel time (pcu*h), where pcu is a passenger car unit. These indicators are directly connected with the environmental impacts of the proposed scheme, which were assessed by the examination of the emission of pollutants and fuel consumption. SATURN uses a linear model with explanatory variables of time, distance, primary and secondary stops. Hence the basic equation for the emission of pollutant i from a link is:

$$Ei = (ai1 * d + ai2 * tc + ai3 * tq + ai4 * s1 + ai5 * s2) * q \tag{1}$$

,where Ei stands for the respective environmental emission under investigation, d is the link distance in kilometers, tc is the average cruise travel time on the link in hours, tq is the time spent “idling” in queues at junctions in hours, s1 represents the total number of ‘primary’ or ‘full’ stops at an intersection; e.g. where a vehicle arrives at the end of a queue, s2 represents the total number of ‘secondary’ stops; e.g. stop-starts while a vehicle moves up in a queue, q is the vehicle flow and ai1-5 are default coefficients concerning each pollutant. These default coefficients have been determined by the model itself through previous research studies (Matzoros 1988, Matzoros et al., 1991) and their values are summarized in Table 1. In order to calculate the environmental impact of each road axis, SATURN sums the values of the pollutants for all the links included in the road. Lead emissions are not calculated in this paper, as these emissions tend to zero.

Table 1: Default parameter values of the five standard pollutants in SATURN

Pollutants	Kilometer	Cruise Hour	Idle Hour	Primary Stop	Secondary Stop
i	αi1	αi2	αi3	αi4	αi5
CO_2 (g/pcu)	70.0	0.0	1200.00	16.000	5.000
CO (g/pcu)	0.0	304.80	180.00	2.22	0.444
NO_x (g/pcu)	0.0	102.60	1.80	0.42	0.084
HC (g/pcu)	0.0	57.00	30.00	0.39	0.078

In order to estimate the total amount of petrol consumed within the simulated network SATURN uses the following equation:

$$f = FLPK * d + FLPH * t + FLPPS * s1 + FLPSS * s2 \qquad (2)$$

,where f stands for the fuel consumption in liters, d is the total travel distance in vehicle-kilometers, t is the total delayed (idling) vehicle-hours, s1 and s2 represent the same numbers as above and the “weighting” parameters FLPK etc. have been assigned default values as follows: FLPK = 0.07, FLPH = 1.2, FLPPS = 0.016, FLPSS = 0.005.

4. Results

4.1. Results concerning the axis of implementation

This section presents the values of the examined parameters referring only to the road axis where the HOV lane was planned and examined. Table 2 summarizes traffic related findings of the research study. The average traffic volume drops after the introduction of the measure, yet only slightly. The drop in the amount of traffic volume is a result of the decreased number of vehicles that carry +2 passengers and are thus allowed in the lane. However, this decrease is partially balanced through the attractiveness of the lane (higher average speed, less average delay) that results in the distribution of more vehicles in the HOV corridor. The marginal traffic volume decline, coupled with the prohibited turning movements to the lane, largely affects the delays in the lane, which is reflected in their reduction by 62%. As far as the average speed in the lane is concerned (including the junction delays), it is substantially increased (from 4.8 km/hr to 11.1 km/hr) in the “after” situation (scenario 2).

Table 2: Values of traffic related indicators in the "before" and "after situation" (reference area: axis of implementation)

	"Before" Situation	"After" Situation	Difference (%)
Average Traffic Volume (pcu/hr)	528	499	-5.59%
Average Speed (km/hr)	4.8	11.1	129.36%
Average Delay (sec)	945	356	-62.32%

In Table 3, the difference in CO2 emissions in the road axis of implementation, before and after the application of the HOV lane, is depicted. There is a remarkable decline of 41.5% in the amount of CO2 emitted in the lane, while the respective drop in CO emissions is also in that area (-42.5%). HC and NOx emissions are also falling significantly in the HOV lane case, by 50% and 66% respectively.

Table 3: Values of environmental indicators in the "before" and "after situation" (reference area: axis of implementation)

	"Before" Situation	"After" Situation	Difference (%)
CO_2 Emissions (kg)	325	190	-41.53%
NO_x Emissions (kg)	3	1	-66.67%
HC Emissions (kg)	6	3	-50.00%
CO Emissions (kg)	40	23	-42.50%
Fuel Consumption (l/hr)	410	243	-40.73%

The total fuel consumption in the proposed HOV lane also decreases considerably. In Scenario 1, it is found to be 410 l/hr, while this figure drops by 40% to 243 l/hr after the application of the HOV lane.

4.2. *Results concerning the buffer zone without the axis of the HOV implementation*

This section demonstrates the impacts of the HOV lane in the buffer zone of the implementation (i.e the adjacent streets to the HOV road axis excluding the analysis of the latter). The buffer zone is evaluated concerning its traffic related and environmental indicators, since it is this zone that will be mostly influenced by a realization of such a project. Within the buffer zone of the scheme lie all adjacent streets of the examined HOV lane, plus two major arterial roads north and south of the proposed HOV lane. Table 4 outlines the transportational impacts of the HOV lane in this zone. It is noteworthy, that the average delay is increased by 7% in the buffer zone, and as a consequence, the average speed drops by 10%. This rise is also affected by the higher length of generated queues due to the increase of the average traffic volume (12,115 pcu/hr to 12,311 pcu/hr). The increase in the traffic volume in the buffer zone does not reflect the drop of traffic volume in the HOV road axis and this occurs due to the distribution of traffic to other routes outside the buffer zone.

Table 4: Values of traffic related indicators in the "before" and "after situation" (reference area: buffer zone)

	"Before" Situation	"After" Situation	Difference (%)
Average Traffic Volume (pcu/hr)	12,115	12,311	1.62%
Average Speed (km/hr)	7.67	6.90	-10.03%
Average Delay (sec)	3897	4172	7.06%

All environmental indicators in the buffer zone are slightly improving after the application of the HOV lane. Table 5 denotes that NOx emissions in the zone are mostly influenced, since the amount emitted decreases by 3.5%. HC emissions remain at the same level they were before the application of the HOV lane (in that case the change is either negligible, thus not quantifiable, or the SATURN emission model does not react sensitively to the new scenario), while CO and CO2 emissions are reduced by 1%. It is here noted, that despite the worsening of the transportational parameters in the buffer zone, the improvement of the respective environmental parameters is explained due to the absorbent of the extra traffic from the two road axes parallel to the one bearing the HOV lane. These axes have the required capacity and thus the ability to carry the extra amount of traffic induced after the implementation of the HOV lane. Hence the generated traffic does not seem to worsen the environmental impacts in the buffer zone.

Table 5: Values of environmental indicators in the "before" and "after situation" (reference area: buffer zone)

	“Before” Situation	“After” Situation	Difference (%)
CO_2 Emissions (kg)	3592	3544	-1.34%
NO_x Emissions (kg)	57	55	-3.51%
HC Emissions (kg)	78	78	-
CO Emissions (kg)	462	457	-1.08%
Fuel Consumption (l/hr)	4656	4606	-1%

4.3. Results concerning the buffer zone including the axis of the HOV implementation

Finally, the overall fuel consumption changes insignificantly in favor of a prospective implementation of the HOV lane. Despite the increase of the average delay in the buffer zone, which is directly connected with fuel use, the overall consumption decreases by 1% (from 4656 l/hr to 4606 l/hr).

Table 6 includes the total environmental impacts of the proposed HOV lane, summing the values of the pollutants and the fuel consumption both in the axis of implementation and the buffer zone. As seen, there is a slight yet considerable reduction in the values of all respective categories.

Table 6: Values of environmental indicators in the "before" and "after situation" (reference area: axis of implementation and buffer zone combined)

	“Before” Situation	“After” Situation	Difference (%)
CO_2 Emissions (kg)	3917	3734	-4.67%
NO_x Emissions (kg)	60	56	-6.67%
HC Emissions (kg)	84	81	-3.57%
CO Emissions (kg)	502	480	-4.38%
Fuel Consumption (l/hr)	5066	4849	-4.28%

5. Conclusions

Among the available tools and policies to constraint the extended private car usage, a growing global trend has been noticed in favor of the HOV lanes. An HOV lane implementation however, is more of a constituent issue of an overall TDM approach. Rather than assessing and evaluating such an effort alone, the whole approach should be taken into consideration; an HOV scheme is a part of the broader travel management picture of a given environment.

Thessaloniki's HOV lane implementation would prove to be an exception to the international experience according to this research. Such a lane has not yet been realized within the CBD area of a city. The outcomes of this enterprise, assessed with the help of a traffic simulation model, proved to ameliorate the traffic and environmental conditions in the road axis of implementation. A significant increase in the average speed by 129% and a noteworthy decline in the average delay by 62%, both implying better environmental results, along with diminished levels of pollutant emissions were among the main benefits of this research study. Fuel consumption's decline by 40% in the examined HOV section fulfils the objectives set by the global sustainability agenda; less energy used, less money spent, better environmental conditions. As far as the buffer zone of the proposed HOV lane is concerned, the traffic related indicators are notably worsening. Both average speed and delay figures deteriorate after the introduction of the measure, only to result in a marginal rise of the values of the respective environmental indicators. Even if this slight improvement of the environmental conditions does not justify a probable implementation of this project, the possibility of realizing the HOV lane should be looked into. That is because if all impacts are taken into consideration, both the positive ones concerning the HOV axis itself, and the neutral ones concerning the buffer zone of the axis, the HOV scheme seems to meet the goals initially set.

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