A Simulation Model for Analyzing Traffic and Environmental Impacts from Heavy Vehicle Movement in Urban Areas

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Abstract

The scope of this study is to examine the impacts of heavy goods vehicle traffic in the Athens downtown area and to evaluate alternative proposals for improving traffic conditions in the area. Simulation is used to derive traffic impacts, using present condition data and applying a number of scenarios (proposals) related to heavy vehicle traffic restrictions. Traffic impacts are measured by changes in the average network speed. A multi-criteria analysis is also conducted in order to evaluate the examined scenarios. This analysis takes into account additional criteria such as environmental and socioeconomic impacts. The results of the study show that application of two of the proposed scenarios would lead in improving traffic conditions in the Athens, Greece, downtown area.

Study's Topic: Heavy vehicles impacts in urban traffic conditions

Key-Words: Traffic impacts, Heavy Goods Vehicles, Simulation, Multi-criteria Analysis

1. Introduction

The present study examines impacts in traffic that are related to the circulation of heavy goods vehicles in the Athens downtown area. Its scope is to propose actions for the improvement of traffic conditions which are nowadays significantly influenced by heavy goods vehicle traffic. These proposals are intended to be embodied in an overall framework of regulations which will aim at controlling and reducing traffic and environmental impacts caused by heavy good vehicles.

According to the existing legislation, heavy goods vehicle circulation and supply of shops in Athens are regulated by acts issued by the Greek Government and the Police. These regulations include restriction zones like:

- The Internal Ring: A number of main arteries surrounding the Athens Downtown area form the "Internal Ring". Depending upon the date, only vehicles whose license plate last digit is an odd or even number are allowed to enter the area within the Ring.
- The Blue Zone: It is an area within the Internal Ring, where there will be further restrictions in the circulation of heavy good vehicles.
- The Commercial Triangle: A part of the Athens downtown area, within the Internal Ring, where no private vehicles are allowed to enter.

as well as limitations to the shops' supply schedule. The emphasis of this study is given to the "Blue zone" characteristics and operation.

It is a fact that heavy good vehicles have negative impacts on traffic, both when moving and stopping. Their impacts depend upon the road's geometry, the traffic composition and pedestrian movements (McShane and Roass, 1990). The results of a past study, conducted by the Greek Ministry of Public Works and the National Technical University of Athens (1999), showed that:

- Most of the vehicles entering or moving around the Athens downtown area are light trucks.
- The main types of goods transported to the Athens downtown area, are fuel and food supplies.
- The main types of goods transported within the Athens downtown area, are food supplies.
- A large number of trucks are empty when circulating in the Athens downtown area.
- Overall, only a fragment of the total capacity of trucks crossing the Athens downtown area is actually used.

2. Methodological approach

The methodology used in the study analyzed the present traffic conditions in relation to heavy vehicle traffic and examined alternative scenarios for determining the optimal "Blue Zone" boundaries and its restrictions. For assessing present conditions, a field survey was conducted. The survey included the collection of information regarding heavy vehicle traffic characteristics in the Athens downtown area, as well as information about the behavior of heavy vehicle drivers with respect to the existing "Blue Zone". In addition, speed and traffic composition data were collected. The above data were necessary to perform a simulation process, described later on.

A simulation process was used to assess the impacts of alternative scenarios, regarding heavy vehicle traffic restrictions, using present condition data as inputs. For the assessment of traffic impacts, changes in travel speeds, in and out of the “Blue Zone”, were examined. The simulation process was properly adapted to the problem needs, so that the best quantification of impacts to traffic could be achieved. The study area not only included the "Blue Zone" but also the "Internal Ring". The reasons for including the “Internal Ring” was the need to evaluate the impacts of the alternative scenarios, in a broader area, directly influenced by the “Blue Zone”.

For the application of the simulation process, the re-estimation of the O-D matrix for the Athens downtown area was considered necessary (Attiko Metro, 1996). The new origin-destination (O-D) matrix was extracted based upon traffic flow composition in selected links of the network and the existing O-D matrix. The existing O-D matrix was derived after an extensive study in the Athens Metropolitan Area. In addition, traffic flow composition data were used for estimating percentages of usage for the following transportation mode categories (Attiko Metro, 1996):

- Private cars -Taxis
- Buses
- Trucks

The new O-D matrix was used in the simulation process for distributing transportation demand to the network’s roads. For the distribution procedure, the differences in the perceived cost of demand among the users of the above modes were also taken into account. For a more realistic representation of each user's behavior, the perceived cost was divided into two components. The first component concerned the cost related to the total travel time (in seconds) in the network’s links, including delays to intersections. The second component concerned the total distance traveled (or passenger kilometers) in the network. The weight attributed to each component for each category was related to the marginal distance traveled by heavy vehicles with respect to the marginal distance traveled by the rest of the vehicles.

The objective of the simulation was to determine the relationship between delays and traffic flow and subsequently the total travel cost in the network’s links. That information was acquired by extracting the minimum cost routes between the network’s origins and destinations. In order to get the minimum cost routes, the relationship between travel time and traffic flow, derived by the flow pattern among links, was used.

The entire procedure applied, was based upon a repetitive technique, a refinement of the “all or nothing” assignment method. The flow produced was imported in the simulation process, queues and delays were recalculated and used in the flow distribution among links. The entire process was repeated until convergence. Convergence was achieved when a steady state balance between the travel times in the links of the network was established. Using the procedure, an area could be analyzed in several levels of detail. Traffic capacity of links and delays in junctions could be estimated with adequate accuracy and used for deriving the relationship between delays and flow for each link.

Impacts in traffic are quantified by parameters such as traffic capacity, average speed, delays, etc. (Hway-Liem, 1988, Hackert et al. 2001) The existing traffic conditions were simulated successfully by properly setting these parameters. Several scenarios were applied, according to possible restrictions in heavy goods vehicle circulation. The scenarios were set up in such a way so that by changing the parameters, the impacts in traffic could be easily obtained. For evaluating the alternative scenarios, travel speed reduction was used as a criterion.

3. Alternative scenarios

The knowledge of the present traffic conditions allows the development of alternative scenarios regarding the "Blue Zone" characteristics. For developing the alternative scenarios, present conditions data, as well as planned large-scale traffic interventions to the Athens Metropolitan Area, were taken into consideration. The scenarios covered alternative cases for the Blue Zone limits and for the percentage of trucks that could enter the Blue Zone. It is noted that the examined scenarios took into account the existing restriction hours for the supply of businesses. Analytically, the following scenarios were examined:

- *Do-Nothing Scenario:* Existing Blue Zone and a percentage of the heavy vehicles, as defined by the traffic data survey, are used.
- *Scenario 1:* Setting new limits for the "Blue Zone". The characteristics of the new "Blue Zone" are as follows: Smaller than the existing one, limited by wide streets, easily memorized by the truck drivers and patrolled by the police.
- *Scenario 2:* Setting new limits for the "Blue Zone". The characteristics of the new "Blue Zone" are as follows: Larger than the existing one, includes areas with extensive traffic problems because of heavy vehicle traffic.
- *Scenario 3:* Application of the existing Blue Zone with real enforcement of its restrictions.
- *Scenario 4:* Abolition of the Blue Zone. This scenario was expected to lead to a significant increase of heavy vehicle traffic in the area. For that reason three sub-scenarios were examined. The first examined the case in which the number of circulating trucks would increase by 50 %. The second sub-scenario examined the case in which the number of circulating trucks would be doubled. Finally the third sub-scenario investigated the traffic and environmental consequences caused by quadrupling of heavy vehicles in the area.

For all five scenarios the traffic and environmental impacts were estimated using the previously described methodology.

4. Simulation Calibration and Validation

In order to describe the traffic conditions under several alternatives, in the most accurate way, the simulation process parameters had to be calibrated. This included setting up the network and its parameters correctly and accurately, defining the O-D areas and the "Blue Zone" for each scenario. Setting up the network meant describing the geometry of each link, its free flow speed, capacity and length. Since the examined network was not very extensive, entrances and exits of the "Inner Ring", were used as origins and destinations. As for the process validation, the results of the simulation differed 10% on average from collected flow data, which was considered acceptable.

5. Traffic and the Environmental Impacts

Traffic impacts for each of the alternative scenarios by importing scenario information and present condition data in the simulation process. That way obtaining quantified results for traffic impacts could be achieved. The simulation process took into account traffic conditions defined by alternative limits for the "Blue Zone" and alternative percentages of the crossing heavy vehicles. The estimation of traffic impacts was described in quantitive terms as the change of average speed in the examined road network.

The application of the alternative scenarios showed remarkable changes in the network. More precisely, redistribution to the flows of the network's link as well as changes in speed, were observed. The percentage changes of the average speed for the alternative scenarios in comparison with the Do-Nothing scenario are summarized in Table 1.

Table 1: Percentage changes of speed by the application of the alternative scenarios

Alternative scenarios	Within Blue Zone	Within the small traffic ring	Limits of Blue Zone
Scenario 1	+ 11 %	+ 0.8 %	- 4.3 %
Scenario 2	+ 16 %	+ 7.8 %	- 7.1 %
Scenario 3	+ 11 %	+ 1.1 %	- 4.7 %
Scenario 4	**Percentage change of speed within Blue Zone in comparison with the Do-Nothing Scenario**		
	Increase of trucks percentage by 50%	Doubling of trucks percentage	Quadrupling of trucks percentage
	- 5.54 %	- 7.23 %	- 8.53 %

It is noted that, for Scenario 1, by limiting Blue Zone, speed increases to 11% and 0.8% respectively, within Blue Zone and the "Inner Ring", while, in the limits of Blue Zone, speed decreases by 4.3%. For Scenario 2, by setting Blue Zone in a wider area, it is noted that speed increases within Blue Zone and the Inner Ring by 16% and 7.8% respectively. On the contrary, speed decreases by 7.1% in the limits of Blue Zone. Scenario 3, a firm application of the restrictions in the existing Blue Zone, led to a speed increase of 11% within Blue Zone and of 1.1% within the Inner Ring. The speed decreases by 4.7% in the limits of the Blue Zone. It is noted that the reduction of average speed in the limits of Blue Zone is a result of the concentration of heavy vehicles in the roads setting these limits. Finally the abolition of the Blue Zone, results to an increase in the percentage of crossing heavy vehicles and leads to significant reductions of the average speed, depending upon the percentage of heavy vehicles that pass from the examined area. The average speeds for the alternative scenarios are presented in Table 2.

Table 2: Average speed rates (km/h) for the alternative scenarios examined

Alternative Scenarios	Within the Blue Zone		Within the small Traffic ring	
Do Nothing Scenario	12.85		20.90	
Scenario 1	Without restrictions	With restrictions	Without restrictions	With restrictions
	11.87	13.31	20.90	21.07
Scenario 2	Without restrictions	With restrictions	Without restrictions	With restrictions
	13.11	15.21	20.90	22.53
Scenario 3	14.26		21.13	

As for environmental impacts, air pollutants related to traffic of both heavy vehicles and other vehicles were estimated for each scenario. The estimation included air pollutants for each mode as well as each mode's contribution to air pollution. These estimates were used for evaluating the alternative scenarios with respect to environmental impacts. The CORINAIR and COPERT methodologies, (Eggleston et al, 1993; Ahlvik et al; 1997), which use the average speed, the vehicles size and age, were used to estimate pollutants.

6. Analysis of the Results of Traffic and Environmental Impacts

The examination of the traffic impacts after applying the alternative scenarios indicated significant changes in the network's traffic and environmental conditions. In terms of traffic, the study of impacts showed significant changes in the average speed of the network. The application of the "Blue Zone" resulted in an increase of the average speed, both in the "Blue Zone" and the "Inner Ring", though the increase of speed in the "Inner Ring" was less on average than in the "Blue Zone". On the contrary, speed decreased in the roads surrounding the "Blue Zone", in all the scenarios examined. This happened mainly because the drivers of heavy vehicles, who are not allowed to enter Blue Zone, tend to move around the limits of the "Blue Zone", causing traffic problems in the corresponding roads.

Taking as granted that the abolition of the Blue Zone would lead to a considerable decrease of the average speed of vehicles, the next step was to examine alternative limiting the Blue Zone. As already mentioned, a variety of alternative scenarios were examined, and three of them were selected for further, in-depth examination. The percentage changes of speed for each of the examined scenarios lead to the conclusion that most benefits in traffic are obtained by applying Scenario 2. If Scenario 2 is adopted, the average speed is expected to increase 16% in the Blue Zone area and 7.8% in the area of the internal traffic ring.

The environmental benefits by applying Scenario 2, were found also significant, especially in secondary roads. Lesser environmental benefits arise by applying Scenario 1. On the contrary, the abolition of the Blue Zone (Scenario 4), leads to considerable increases in pollutants.

7. Evaluation of Alternative Scenarios

By combining traffic and environmental impacts, Scenario 2 seems the most appropriate. Despite that, because of the expected social and economic consequences, as well as the practical difficulty of enforcing Scenario 2, it is necessary to take additional factors into consideration. On the contrary, socioeconomic consequences seem less important when applying Scenario 1, since the "Blue Zone" area is reduced in size. A small area, where heavy vehicle traffic is banned, makes it easier for the police to patrol and consequently for the restrictions to be enforced.

Therefore, the best scenario had to be selected through a multi-criteria evaluation of all parameters that could influence the success of the "Blue Zone". These criteria are the following:

- *Traffic impacts within the limits of the "Blue Zone":* The impacts are the results of the simulation process, this means the average speed reduction
- *Environmental impacts within the limits of the "Blue Zone"*: The impacts in pollutant reduction for every proposed "Blue Zone" area.

- *Traffic impacts within the "Inner Ring"*: The impacts are related to the average speed reduction in the "Inner Ring", according to the simulation's results.
- *Environmental impacts in the "Inner Ring":* The impacts in pollutant reduction to the "Inner Ring", for every proposed "Blue Zone" area.
- *Socioeconomic impacts:* These include possible protests of the shopkeepers and employees within the area defined by the Blue Zone, as well as the protests of the trucks' owners.
- *Ability of Comprehending:* How easy it is for the heavy vehicles drivers to comprehend and respect the "Blue Zone".
- *Ability of Enforcing:* The ability of enforcing the "Blue Zone" for each scenario.

From the initially proposed scenarios, three were selected based upon the results of the traffic and environmental impacts. Scenarios 1,2 and 3 were the scenarios selected to be analyzed further on. Scenario 1 proposed a smaller "Blue Zone", Scenario 2 proposed a larger "Blue Zone" and Scenario 3 kept the existing "Blue Zone", with strict enforcement. For the above criteria, the three scenarios examined were rated from 1 (best) to 3 (worst). For instance, for the criterion concerning the traffic consequences in the Blue Zone, Scenario 2 was rated as the best solution (1) since the increase of the vehicles' average speed was the largest observed. Scenario 3 as well as Scenario 1 were rated with 2.5 since both of them resulted to the decrease of the vehicles' average speed within the proposed "Blue Zone". Then, the rating of each alternative for each consequence was calculated as the average of all rates for each Scenario. It is noted that all impacts were considered equal in weight, based upon expert judgment. An analytical presentation of the multi-criteria procedure for the choice of the Blue Zone range is shown on Table 3.

Table 3: Multi-criteria analysis for the proposed Scenarios

	Scenario		
Criterion	1	2	3
Traffic impacts in Blue Zone	2.5	1	2.5
Environmental impacts in Blue Zone	2.5	1	2.5
Traffic impacts in Inner Ring	3	1	2
Environmental impacts in Inner Ring	2	1	3
Socioeconomic impacts	1	3	2
Ability to comprehend	1	3	2
Ability to enfoce	1	3	2
	1.859	**1.859**	**2.288**

The total rating of the three alternative scenarios is shown in the above Table's final row. It is noted that the lowest rating corresponds to the best selection, while the highest rating to the worst one. Consequently the results of Table 3 show that Scenarios 1 and 2 are the best, each one having its advantages. Scenario 2 is superior with respect to traffic and environmental issues while Scenario 1 is superior to socioeconomic impacts, and limits comprehension and enforcement issues. It is noted that keeping the Blue Zone to its existing limits with strict enforcement is the least preferred choice. There is however a "political" dimension concerning the exact definition of the Blue Zone limits which was not examined in the framework of the present study.

8. Conclusions

The conclusions show that the most favorable Scenarios for application are Scenarios 1 and 2. The first one proposes the creation of a smaller Blue Zone while the second expands the existing one, so as to include areas with intense traffic problems. Despite the fact that Scenario 2 is far better with respect to traffic and environmental issues, other factors make Scenario 1 equally attractive for application. The proposed scenarios must be incorporated in an overall approach for the management of the Athens Metropolitan area transportation system. The above analysis shows that the proposed scenarios can contribute positively to the traffic and environmental conditions in the Athens Downtown Area.

It would be particularly interesting to examine the influence of the “Blue Zone” scenarios, in combination with the rest of interventions to the transportation system (especially interventions concerning parking, shopping hours and establishment of exclusive bus lanes), so as to quantify the total influence which is expected to be different. The proposed methodology can be exploited for the combined evaluation of the influence of any type of changes in the Athens Transportation System.

Finally an integrated plan for patrolling the limits and the area of the “Blue Zone”, in combination with an effective system of penalties, is absolutely necessary so that the application of the proposed Scenarios will not fade. In parallel, the sufficient and clear marking of the examined area might minimize the possibility of non-informed drivers about the arrangements. The adoption of the proposals might lead to a more friendly system of Heavy Goods Transportation in the Athens downtown area, both for traffic and environment.

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