Effects of Urban Delivery Restrictions on Traffic Movements

Dr. George Yannis[1], Dr. John Golias[2], and Dr. Constantinos Antoniou[3].

Abstract

This research investigates traffic and related impacts linked to the adoption of restrictions in vehicle movements associated with urban delivery operations. A wide range of data (including land use, delivery requirements per type of service, traffic mix, traffic flows and capacities) are input to suitable models for the assessment of traffic and environmental impacts in the city of Athens, Greece. The findings suggest that restricting delivery to specific types of businesses during rush hours can lead to positive traffic and environmental impacts. The effectiveness of urban delivery restriction policies depends on the careful selection of the time periods and types of businesses for which they will apply.

Key words: urban traffic, urban delivery operations, traffic impact, heavy goods vehicle traffic, delivery restrictions

[1] Corresponding author, Assistant Professor, Department of Transportation Planning & Engineering, National Technical University of Athens, 5 Iroon Polytechniou str., GR-15773, Athens, Greece, phone: +30.210.7721326, fax: +30.210.7721454, e-mail: geyannis@central.ntua.gr
[2] Professor, Department of Transportation Planning & Engineering, National Technical University of Athens, 5 Iroon Polytechniou str., GR-15773, Athens, Greece, e-mail: igolias@central.ntua.gr
[3] Research Associate, Department of Transportation Planning & Engineering, National Technical University of Athens, 5 Iroon Polytechniou str., GR-15773, Athens, Greece, e-mail: antoniou@central.ntua.gr

1. INTRODUCTION

Urban traffic congestion and related impacts constitute a major problem in large cities worldwide. The traffic and stopping of vehicles serving the urban delivery operations is a well-established contributing factor [1], having a direct impact on the traffic capacity of the road axes [2]. More precisely, stopped vehicles reduce the traffic capacity of the affected links, given that fewer vehicles can pass the road cross-section during the unit of the time. Goods collection and delivery trucks (typically heavy vehicles) also contribute to the degradation of the traffic conditions through their movements on these axes.

The resulting capacity reduction depends on the geometric characteristics of the road (number and width of lanes, distance downstream junction, grade of slope, etc.) as well as on the width of the vehicle occupying the pavement and the traffic composition. The reduction of the saturation flow lasts for as long as the vehicle is parked but its impact on the traffic conditions may last for a longer period [3]. The negative traffic impacts concern the increase of delays for passing the specific section of the road, and consequently the decrease of the average speed. The respective environmental impact concerns the increase of atmospheric pollution due to the deterioration of the main traffic parameters [4].

Han et al. [5] use a geographically based combinatorial model to estimate the extent of capacity losses and subsequent delay from illegal parking of delivery trucks. Han et al. [5] found that traffic disruptions due to pick-up and delivery rank third in total annual delay for all motorists (after crashes and work-zones, and higher than breakdowns and adverse weather conditions). It is noted that among these five top delay-causing events, pick-up and delivery is the only one that is deliberate. Several approaches that have been proposed to overcome this issue (including off-peak delivery, on-street delivery restrictions) are reviewed next.

Holguin-Veras et al. [6] investigate the potential of off-peak deliveries, giving particular attention to the perceptions of the involved shareholders. Their recommendations include carrier-centered initiatives, e.g. off-peak delivery permits that would ease parking restrictions, and incentives to receivers committed to do off-peak deliveries. Furthermore, Holguin-Veras et al. [6] mention that several companies choose to make off-peak deliveries, mainly because in this way they can increase the efficiency of their delivery operations by avoiding traffic delays.

Churchill [7] describes an off-peak delivery experiment that took place in London in the late 60s. The findings indicate that, one of the contributing factors in order for off-peak deliveries to be successful is that the shippers and receivers must perceive a real benefit to them. Grenzeback et al. [8] studied off-peak deliveries as a way to decrease the congestion in California's freeway system. Their findings suggest that the long-term impact in terms of traffic congestion would be modest, as initial travel time savings would lead to an increase in other traffic, there would be positive effects on air quality, and that off-peak deliveries would translate into additional costs to shippers and receivers.

In 1983 the Greater London Council appointed the Wood Committee to examine the case for introducing a night ban on trucks with a gross weight in excess of 16.5 tonnes [9]. One of the Committee's key findings was that most of the articulated vehicles entering the city were only partially loaded and therefore could be replaced by smaller vehicles (without increasing the overall number of vehicles). A direct substitution of smaller vehicles for larger ones could clearly save money and benefit the environment. The London "night lorry ban" was introduced in 1984. The effectiveness of the measure was weakened by the large number of exemptions granted to firms delivering within the city and the low level of enforcement [10].

Variable use of the existing on-street parking space is a different approach in which delivery operations during peak hours are restricted for the direction with the heavier traffic. In order to maximize the potential for success, the appropriate criteria for the size of the delivery vehicles and the selection of the zones where variable use of the on-street parking space applies should be examined, set and enforced by public authorities in collaboration with the concerned companies [11]. A pilot application of variable use of on-street parking space has been successfully completed in Barcelona in 2000. Variable message signs installed in the roadside indicated who is allowed to use the street (resident parking, deliveries, no parking) at any given time [12].

Finally, other, more elaborate, schemes have also been proposed. Structural changes in the urban distribution system can lead to significant improvement of traffic conditions in the city centers [13]. For example, the development of networks of urban logistics warehouses operating with the hub-and-spoke system, where shipments are forwarded by large trucks to warehouses at the outskirts of the city and then distributed to the city shops by smaller vehicles could have positive impact to traffic and environmental conditions. (On the other hand, other aspects of using smaller vehicles, such as the likely increase of energy use per ton delivered, should also be considered). Replacing large trucks by smaller ones or vans may lead to important improvement of traffic conditions and of related noise levels, given that smaller trucks are more friendly for traffic and environment [14].

Very often, traffic impacts from delivery operations are treated through combined measures. In New Orleans several changes in the urban delivery system took place including night deliveries, delivery zones, standards for off-street delivery space requirements for new shops, enforcement of delivery rules, merging distribution centers, use of new technologies, as well as education and information campaigns to all persons involved in the city delivery system [15]. Other alternatives have also been examined, such as underground freight transport systems and electric urban delivery vehicles [16].

Interestingly, while important research was carried out world-wide in the logistics and organisational aspect of urban deliveries (e.g. [17,18,19]) little attention has been devoted towards the quantification of the traffic impact due to the application of specific schemes for urban deliveries [8,20].

A methodology for the quantification of the traffic impact due to urban delivery restrictions is presented in this paper. The impact of alternative restriction policies aiming to reduce the deterioration of traffic and environmental conditions caused by delivery operations is examined. The associated social and economic costs are also considered in the evaluation of the proposed restrictions.

2. METHODOLOGY

The assessment methodology for the impact of urban deliveries' restriction policies is shown in Figure 1. The methodology is developed along two parallel tracks. The first track aims at establishing the base case. Collected data are used to develop the base network and calibrate the simulation model, capturing reference conditions. The simulated conditions are verified against best available traffic measurements and the calibration of the model is not completed until there is a reasonable match between simulated and observed conditions.

[Insert Figure 1 about here]

The traffic assignment model that was selected for the purposes of this research is SATURN [21]. SATURN is a well-established model, which is suitable for the simulation of large urban networks. The ability of the calibrated model to replicate the traffic conditions in the base case was an indication of its appropriateness for this application. In particular, simulated traffic flows were within 15% of the measured flows, with an average deviation around 10%.

The traffic mix and stop patterns were determined from a combination of the traffic mix measurements, the interviews with the actors and the OD matrix. OD matrices for the considered vehicle classes were extracted from the AMDS data (reflecting all vehicles in the entire Athens metro area). This matrix was assigned to the network and the resulting vehicle mix per artery was validated against the interviews and the traffic mix measurements. Traffic mix covered all the basic vehicle classes (two-wheelers, passenger cars, pick-up trucks, trucks and buses) as well as the specific classes that served the considered delivery functions (e.g. garbage collection trucks, gas delivery trucks, school-buses). The contribution of the delivery and collection vehicles to the traffic conditions was estimated at the individual class level.

Traffic data and other relevant information –such as vehicle mix and network characteristics- are used by an environmental model to output emissions for the reference scenario. Other models that exploit these outputs may also be incorporated at a future stage to capture different aspects of the problem.

The second track simulates the performance of each considered scenario. Each scenario is modelled as a set of restrictions to the delivery process. These restrictions are input to an algorithm that computes the resulting capacities, which are then used for the generation of the modified network. This modified network -along with other inputs such as the network demand- is used for the computation of the traffic performance of each scenario of restrictions. The output of this model is used for the estimation of environmental and socioeconomic impacts.

The impact of the delivery restrictions on the network is taken into account in the simulation model by changing the link capacities on the basis of the intensity of delivery operations along the links. For this to be possible, the land uses along each link were taken into account [22] and were grouped on the basis of similar delivery needs per land use. The grouping was based on a thorough survey, consisting of on-site counts and interviews, which related the land use to the frequency of delivery, as well as to the size of the delivery vehicle and the length of the time period the vehicle is required to stop to complete the delivery.

Thus, for each land use group the average time period per hour that a delivery vehicle is parked on the road can be calculated. For one-way roads the final outcome is based on calculations that consider all land use groups together, while for two-way roads the calculations are carried out for each direction separately on the basis of the land uses corresponding to the suitable side of the road.

The adoption of a delivery restriction scheme for a link leads to an increase of the link capacity, due to the fact that no delivery vehicles will park on the street. This increase is quantified by taking into account in the conventional traffic flow theory calculations the fact that a certain width of the road, which was occupied by delivery vehicles for a certain time period - different widths and time periods for different vehicle sizes - is according to the proposed scheme free for traffic. These changes of capacity per link were introduced in the simulation model, which was subsequently used to quantify the impacts of the proposed restriction scenarios in a macroscopic level.

The following measures of effectiveness were collected from the traffic simulation model for each considered scenario:

- Total travel time (vehicle-hours/hr)
- Total distance travelled (vehicle-km/hr)
- Mean speed (km/hr)
- Mean distance per vehicle (km/hr)
- Mean trip time (min/vehicle)

The traffic data was then used for the estimation of environmental impacts of the proposed restrictions. A two-level environmental analysis was performed. First, the emissions per link and time-period were estimated. Using these emissions as inputs, it was then possible to estimate environmental pollution levels. The difference in these pollution levels was used as the indicator of environmental impacts. The following data was used as input for the environmental models:

- Hourly traffic flows (per link)
- Mean vehicle speeds (per link)
- Traffic mix (per hour and link). For this purpose five vehicle classes were considered: two-wheelers, passenger cars, taxis, buses and heavy vehicles.
- Fleet composition: data from the Association of Automotive Importers of Greece were used to classify each vehicle class into subdivisions, based

on the technology and the displacement of their engine. For example, passenger cars were classified in those using catalytic converters and conventional ones, with each of these categories further subdivided into subclasses, based on engine displacement and age. Different coefficients correspond to each category and consequently, passenger cars of different categories are producing different quantities of gas pollutants [23].

The CORINAIR methodology [24] was used for the calculation of the emitted quantities of gas pollutants.

Finally, the impact of the delivery restrictions is obtained through a multi-criteria comparative analysis covering the traffic, environmental and other related performance of each scenario relative to the reference case. Considering multiple aspects of the problem is essential in evaluating the considered restriction policies, since delivery of goods and persons has a multitude of socio-economic impacts. For example, a very aggressive ban on deliveries throughout most of the day might have positive traffic and environmental impacts, but could also significantly increase the costs of delivery (and thus refuelling, restocking, etc) for businesses.

3. CASE STUDY SETUP

3.1. Study Area

Athens, a city of 3.7 million inhabitants and an area of 1470 km^2, with infamous traffic congestion and environmental pollution problems, was selected as the study area. The analysis was focussed in the area within Athens' outer ring, which includes virtually the greater Athens area. In Athens, urban goods movements and traffic in general, are currently subject to a number of restrictions, illustrated in Figure 2 and summarised as follows (in increasing order of restriction):

- Inner ring: The general vehicle fleet is allowed to circulate in an area inside Athens, called the "inner ring", every other day on the basis of the last digit of the number plate (odd and even dates and digits).
- Blue ring: Truck traffic is restricted from entering from 07:00 to 14:30 and from 17:00 to 21:00 in an area within the inner ring, called the "truck blue ring".
- Historical triangle: All traffic is banned at the historical triangle of the center of Athens, with the exception of delivery trucks during the following two periods: 07:00-10:30 and 14:00-17:00.

The coded network included the inner ring and most of the outer ring of the Athens area. In particular 68 main axes connecting the inner ring with the peripheral centers were modelled, thus capturing most of the movements of interest. The network was represented as a node-link graph, where each link is defined by the upstream and downstream nodes. Speed, capacity and length were the key attributes of each link [25].

[Insert Figure 2 about here]

3.2. Data Collection

The data requirements of the presented methodology are considerable, including exhaustive land use and traffic composition data for each considered link, distribution vehicle stop patterns. Available data from existing data sources was supplemented with data from specially designed surveys.

An accurate representation of the geometry and the traffic conditions of the study network was developed. Data from two main sources -the Athens Metro Development Study, AMDS, [22] and the regular traffic measurements of the Ministry of Public Works- were fused for this purpose. AMDS provides a very detailed land-use database (including 1.700.000 links and 117.000 nodes) for the entire Athens metropolitan area. Based on this information it was possible to extract land-use per link or building block (it should be noted that blocks in Athens, are typically a lot smaller than in the U.S.).

Geometrical data includes link lengths and widths, number of lanes, intersection representation. Operational characteristics include flows, traffic mix, and speed per link. A series of crosschecks and reality checks were performed to manually validate the data.

Heavy vehicle traffic significantly impacts traffic flow, especially in downtown areas. Unfortunately, existing traffic mix data in the study area did not distinguish between trucks and buses. Therefore, a series of traffic-mix measurements was performed in selected links. Links leading in and out of the study area were selected, along with internal links. The locations and times for the measurements were selected in order to obtain a representative sample. The measurements were conducted using cameras and subsequent analysis of the collected video.

The resulting network includes 1330 links and is divided in 285 traffic analysis zones. Time-dependent origin-destination (OD) matrices have been derived from the AMDS (the dimension of each matrix is 285x285). For the purposes of demand representation, six time periods have been distinguished. In particular, separate OD matrices were defined for each of the following time periods:

- 23.00 - 7:00
- 7.00 - 10.30
- 10.30 - 14.00
- 14.00 - 16.30
- 16.30 - 19.00
- 19.00 - 23.00

The assessment of the present condition was focussed around the determination of the land-use patterns and activity intensity per link, as well as the determination of the stop and traffic pattern of the distribution vehicles. Particular attention was given to the intra-day and intra-week fluctuations.

Land-use classes of interest were classified into six categories: super-market, department stores, drugstores, gas stations, restaurants and coffee shops, and other stores (including stores not classified into any of the other 5 categories). The accuracy of this data (type of business as well as location) was confirmed based on crosschecking with other databases and random checking of a subset of these locations.

Distribution vehicle stop patterns were determined through a series of surveys and on-site measurements. Surveys were targeted at a representative sample of companies, covering all sizes, functions and operating status. Individual surveys were prepared for each type of company, so that the qualitative and quantitative characteristics of the stop patterns at each type of store could be assessed. Store interviews were classified in the following types, based on the type of deliveries that they generate:

- Food deliveries
- Non-food goods deliveries
- Construction material distribution
- Sanitary and hospital material
- Liquid fuel
- Garbage collection
- Personnel transport
- Student transport (school buses)

The surveys covered the delivery operations, including type of vehicle, time, duration, and frequency of delivery. Interviews of selected delivery companies were also performed and their results were used as a control reference.

Surveyed companies were selected so that a representative sample of each type of business. On-site measurements were also performed in selected stores. Again, the locations were selected so that each type of activity and size of business is represented equally in the sample.

3.3. Experimental Design

The detailed analysis of traffic characteristics in the study area allowed for the assessment of alternative scenaria concerning the restrictions of delivery operations in combination to the evaluation of socio-economic impacts. The formulation of alternative scenaria was conducted in consultation with the responsible authorities and took into consideration all forthcoming large scale interventions in the study area.

The proposed scenaria concern commercial shops (including super markets and department stores) and food shops, even though several other types of operations were considered (distribution of building materials, sanitary and hospital material, liquid fuel, pick-up of garbage, etc.). The detailed analysis of the operations not finally retained in the proposed scenaria showed that they do not produce any significant impact to the traffic and the environment, mainly due to the limited role of the corresponding vehicle fleet within the total traffic composition of Athens.

In the comparison of results with and without delivery restriction measures, emphasis is given to the morning peak traffic hours and secondary, to the afternoon peak period, during which traffic impacts due to delivery movements are expected to increase. On the basis of the detailed analysis of the shops delivery characteristics in Athens, it was clear that almost all delivery operations are completed before 17:00. Consequently, it was decided not to include in the scenaria any restrictions concerning the evening peak period (19:00 - 21:30).

The following three scenaria were considered:

- **Base case**: Existing situation without any additional restrictions.
- **Scenario 1**: Delivery is restricted during morning (7:00-10:30) and afternoon (14:30-16:30) peak hours of working days (Monday to Friday) for all commercial shops (including super markets and department stores) and for food shops.
- **Scenario 2**: Delivery is restricted during morning peak hours (7:00-10:30) of working days (Monday to Friday) for super markets and department stores only.

4. RESULTS

For the above scenaria, traffic, environmental and socio-economic parameters are evaluated, as presented in the following sections. In order to avoid dilution of the impact of the restrictions (by considering the entire day), the time period from 7:00 to 16:30 was considered for all cases.

4.1. Traffic Impact

While the simulation model provided several measures of effectiveness of the considered scenaria (e.g. average trip time and average distance travelled), average speed was selected for the quantification of their impact. This choice is justified as average speed captures delays, which is perhaps the most adverse traffic impact. Furthermore, it is consistent with the literature [5].

Table 1 summarizes the expected change of the average speed due to the implementation of the delivery restriction measures, expressed as percentage changes from the reference scenario. The results are intuitive, with delivery restrictions resulting in increases in average speed. Furthermore, average speed dropped during the time period for which no restrictions were imposed, presumably because deliveries (that in the reference scenario would take place in the restricted time periods) were rescheduled for this time period.

[Insert Table 1 about here]

In particular, for the first scenario the average speed increased by 4.7% for the period 7:00-10:30 and 1% for the time period 14:00-16:30. On the other hand, the average speed for the time period where no restrictions are imposed decreased by 5.8%. The travel time increase from the delivery restriction for the morning peak period is higher than that for the delivery restriction in the afternoon. This is a reasonable finding considering that the traffic congestion in Athens is a lot more severe during the former period.

The increase in average speed during the periods of restrictions is accompanied by a decrease in average speed in the time period between these two. This can be interpreted by the fact that deliveries that would otherwise be made during the restricted time periods need to be accommodated, and are thus reassigned to this time period.

The average speed decrease during the time period 10:30-14:00 is similar to the combined average speed increases obtained during the two time periods with delivery restrictions. One would be tempted to argue that the two phenomena cancel out. This, however, is not the case since the speed increases during the peak periods (7:00-10:30 and 14:00-16:30), when traffic conditions are more adverse and more vehicles are in the streets, result in an overall decrease in total delays that is higher than the increase in total delays due to the average speed decrease between 10:30 and 14:00.

It should also be noted that the afternoon peak period in Athens is observed later in the day, i.e. outside of the simulated time period. However, the number of deliveries made during that time period is very low. A delivery restriction scenario for that time period would thus have negligible effects, and therefore has not been considered.

Similar trends are observed from the simulation outputs for the second scenario. The average speed increases by 2.6% during the period with delivery restrictions (7:00-10:30), and is accompanied by a slight decrease (less than 1%) in average speed in the next time period (10:30-14:00) and no distinguishable impact on the following time period. The impact of this scenario is lower (in terms of absolute average speed changes) because of the limited scope of the restrictions that did not include food stores (which were included in the first scenario).

As anticipated, the delivery restrictions resulted in an increase in average speed for the time period of effectiveness. The deliveries were also shifted to other time periods, resulting in moderate decrease in the average speed. However, since the traffic conditions during this time period (10:30-14:00) are less adverse, the restrictions policy results in a decrease in the overall delay.

4.2. Environmental Impact

The environmental impact of the considered policies is assessed in terms of a number of estimated pollutant emissions, namely carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (VOC), sulphur dioxide (SO_2) and particulate matters. The emitted pollutants were estimated for each network link in the entire network. The change in the pollutant levels due to each of the considered delivery restriction scenarios is summarized in Table 2**Error! Reference source not found.**.

[Insert Table 2 about here]

Carbon monoxide emissions were affected the most from the restrictions, followed by moderate changes in the hydrocarbons and sulphur dioxide emissions. Percentage changes in nitrogen oxides and particulate matters were negligible.

Emissions decreased by the same amount for both scenarios during the 07:00-10:30 period: carbon monoxide decreased by 9%, while hydrocarbons and sulphur dioxide decreased by 5%. Emissions also decreased in the first scenario during the 14:00-16:30 period: carbon monoxide decreased by 3%, hydrocarbons decreased by 2% and sulphur dioxide showed a marginal decrease of 1%. The magnitude of this decrease, compared to the larger decrease estimated for the morning peak, is intuitive, since traffic conditions in Athens during this time period are not as adverse, and therefore the gains obtained from the delivery restrictions are less evident. Emissions for the second scenario for this time period (14:00-16:30) did not show a change from the reference scenario since there were neither restrictions during this time period, nor secondary effects from the restrictions during the morning period.

These secondary effects did however have an impact in the pollutants emitted during the 10:30-14:00 time period, which consistently increased. For scenario 1, carbon monoxide increased by 7%, while hydrocarbons and sulphur dioxide increased by 5%. The increase for the second scenario was roughly half in magnitude. The increase in the emissions is intuitive and is associated with the rescheduling of delivery operations to circumvent the imposed restrictions. This also explains why in the second scenario, when deliveries are only restricted in the morning time period, the increase in the emissions in the 10:30-14:00 time period was more moderate.

Table 2**Error! Reference source not found.** also shows the percent change in pollutant emissions for the entire study period (07:00-16:30). Overall, there is a reduction of the total pollutant emissions of CO, VOC and SO_2, as a result of both scenarios. It is interesting to note that the total reduction for the second scenario is marginally greater than that of the first scenario, although scenario 2 is related to less restrictions in delivery activities both in terms of time periods and of types of shops. This result seems to indicate that the final environmental balance is very sensitive and extremely influenced by the restrictions imposed and that the actual outcome may not always coincide with what was intuitively expected. One possible explanation may be found in the fact that the environmental balance is also influenced by the prevailing atmospheric conditions, which may magnify the positive or negative impacts during a certain time period, influencing possibly the total result towards an unexpected direction.

5. CONCLUSION

The overall assessment of traffic and environmental impacts from the introduction of delivery restrictions for the city of Athens indicates that spectacular congestion and pollution improvements should not be expected as a result. As expected, while delivery restrictions during peak traffic hours in Athens lead to traffic and environmental improvements during these periods, a respective deterioration is observed outside these periods, when the restricted delivery activities need to be accommodated.

However such restrictions may be justified when their socio-economic impacts are also considered [11,26,27]. The proposed delivery restrictions are not expected to alter the turnover of the stores, as they will only require limited adaptations of the actual delivery system (mainly extension of the shift of a small number of employees). The impact from these delivery restrictions is expected to be more important for the shippers and the forwarders. However, given that transport cost is compressed due to intensive competition, any change in the final price of products will eventually be absorbed through the re-engineering of their distribution system. The proposed restrictions are thus not expected to bring any real economic change both in the microscopic and macroscopic level.

In terms of social impact, the introduction of delivery restrictions is expected to affect two categories of citizens: a subset of employees involved in the delivery operations and people living close to the affected establishments. The small changes in the work-pattern of a limited number of personnel (both in stores and in shippers/forwarders) is likely to be counterbalanced by the addition of overtime wages. The most important social impact may be due to the noise produced by the increased unloading operations during the night. However, it is noted that this phenomenon already exists today, given that a significant part of the delivery of dairy and fresh products takes place before 07:00 in the morning.

Besides confirming the anticipated impacts through a concrete methodology, this research provides a significant contribution as it quantifies these impacts. This type of information is crucial prerequisite in the decision-making procedure and can be used to justify (or discourage) policy decisions. The percentage changes in mean speed of traffic and in the emissions of pollutants due to the application of the proposed delivery restrictions are thus important not only for Athens but also for other large cities with similar problems, to the degree that these figures may give preliminary information for the quantified impacts of similar restriction scenarios. As a consequence, while no claim of transferability is made, the obtained results may constitute an indicative starting point for the elaboration of delivery management systems in other cities.

The final evaluation of alternative restriction policies for other cities requires more accurate impact quantification. This paper presents the application of a methodology, which on the basis of detailed information (including land use information, delivery characteristics per land use category, traffic flow and traffic composition characteristics) and through the use of suitable existing traffic and environmental models may lead to such quantification. The presented methodology is flexible and can be adapted to the particular characteristics and requirements of any conurbation to provide an estimate of the expected traffic and environmental impacts due to interventions in the existing delivery system. Different traffic and environmental models can easily be used, and other types of models can also be incorporated to shed some light to special characteristics of a particular area.

It should be noted that delivery restriction policies might be more effective if they are incorporated into integrated transport and traffic management schemes. For instance, more pronounced improvements may be obtained when delivery restrictions are combined with measures such as parking management, promotion of public transport, land use and working schedules management. The proposed methodology can also be used for the combined assessment of impacts due to the delivery restrictions and any combination of the above additional interventions, leading thus to interesting results for the quantification of the overall improvement (which clearly is not equivalent to the sum of the individual impacts).

As a concluding remark, it is stressed that the success of any restriction system concerning urban deliveries depends to a large degree to careful planning and gradual implementation. Supporting activities can also greatly improve the benefits and minimize the adverse impacts (especially during the short-term transition period). Promotion and information campaigns should be combined with enforcement strategies, which should progressively be intensified, allowing for the appropriate adaptation of the final users.

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[Yannis et al.] Table 1. Percentage change of average speed

	Scenario 1	Scenario 2
7.00 - 10.30	+ 4.7 %	+ 2.6 %
10.30 - 14.00	- 5.8 %	- 0.9 %
14.00 - 16.30	+ 1.0 %	0.0 %

[Yannis et al.] Table 2. Percentage change of basic pollutant emissions

Time period	Carbon monoxide (CO)		Hydrocarbons (VOC)		Sulphur dioxide (SO_2)	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
07:00-10:30	-9%	-9%	-5%	-5%	-5%	-5%
10:30-14:00	7%	3%	5%	2%	5%	2%
14:00-16:30	-3%	0%	-2%	0%	-1%	0%
07:00-16:30	-3%	-3%	-1%	-2%	-1%	-2%

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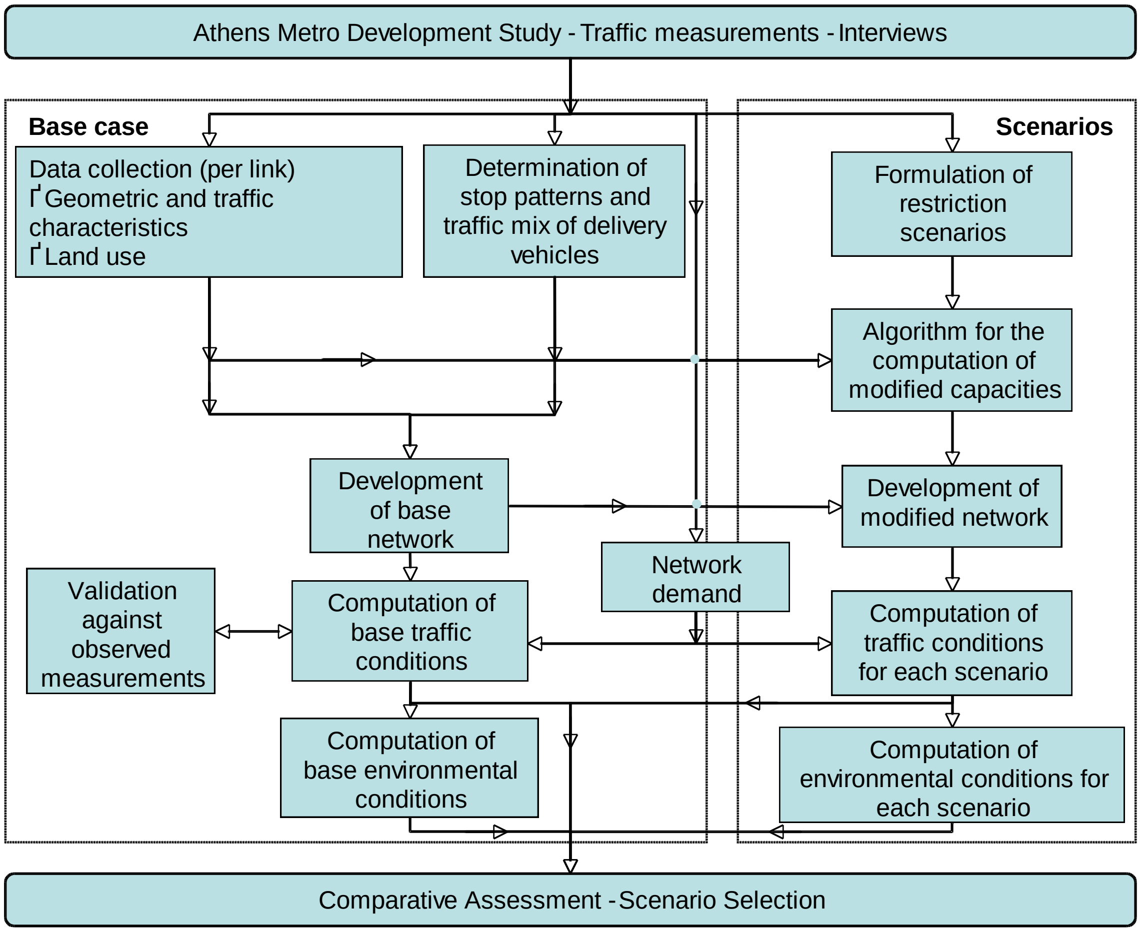
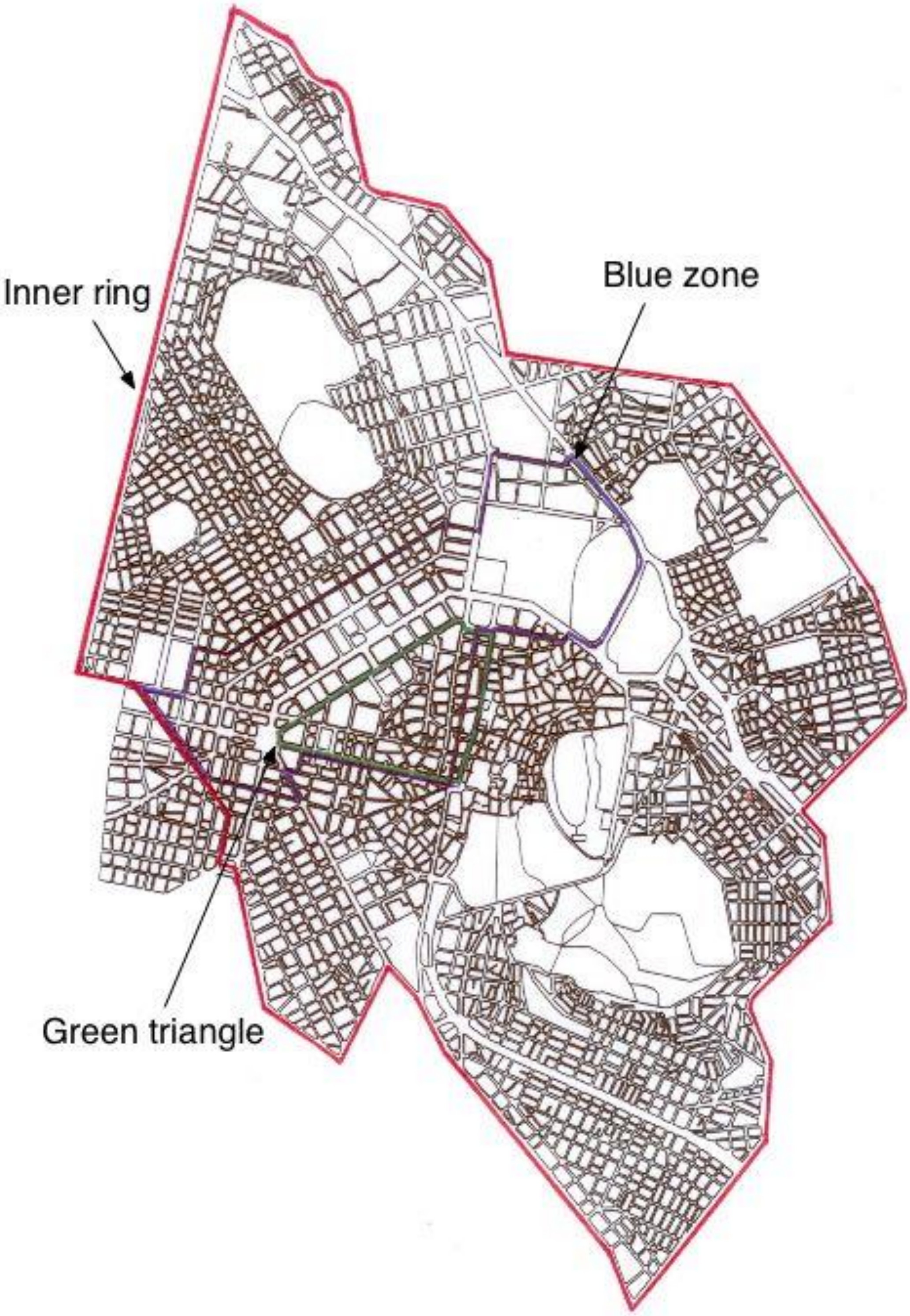


[Yannis et al.] Figure 1. Methodology overview



[Yannis et al.] Figure 2. Study network map