Assessment of traffic and emissions impacts, for determining future infrastructure in a metropolitan street network: A real application in Mexico City

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Abstract
We present an approach for assessing traffic and emissions impacts which are generated by large modifications to the metropolitan street network, for several current and future time scenarios. We include a multicriteria analysis for determining the best set of modifications for each time period. This approach uses an User Equilibrium Model, MOBILE, Electre Method and a GIS-T, and it is based on link level. The approach was applied to the Mexico City case, and the first set of recommended large modifications to the network, were already built.

Introduction

Several changes occur in a metropolis and most of them have a direct impact on traffic, congestion, emissions, urban image and environment. The main infrastructure changes can happen on the streets network and on the land use (for example, due to real estate developments). However, in a developing country, the cities grow without order, and this growth could be both legal and illegal, which produce residential, industrial and services zones without the minimum required road infrastructure and with huge congestion and environmental problems.

Usually, before an urban infrastructure change takes place, traffic and environmental impact studies are required by the municipality, however each study is focused on a small zone or

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corridor, and is not even linked to similar studies for other modifications into the same zone.

Any modification on the street network, such as the arcs improvement or the new arcs construction, tries to diminish congestion. However it is not easy to decide what modification is the best. Often the local government has a set of candidate modifications to the network, each one with its corresponding impact.

Our objective is to propose an approach for analyzing the impacts (on congestion, emissions and urban image - environment) of a large infrastructure modification on the whole metropolitan zone, for future scenarios of "real" growth of the city, and choosing the "best" set of network modifications according budget. We present a recent application to the Metropolitan Zone of Mexico City (MZMC) case.

State of Art

There are few studies about the assessment of the performance of a metropolitan network and its environmental impact, and even though the impact of a street network modification could reach large distances, most of the studies assess the traffic and environmental impact just on a corridor or a predefined small network. Ambrosino *et al.*, (1999) proposed a methodology for analyzing the impact of transport measures, by means of indicators on mobility, energy and pollution, estimated for macrozones (traffic zones) and corridors. Klungboonkrong and Taylor (1998) developed a Decision Support System (DSS) for a multicriteria (difficulty of access, noise level and pedestrian security) assessment of environmental impact. They obtained indicators for each arc of the network, in order to identify the arcs with the worst environmental problems. Arampatzis *et al.*, (2004) developed a DSS for the analysis and evaluation of different transportation policies. The evaluation of each scenario was based on traffic, environmental and energy indicators. A traffic assignment model was used for determining the traffic indicator, while energy consumption and emissions were calculated by means of COTINAIR group methodology. The multi-criteria analysis was based upon judging over appropriate weighted criteria indicators.

Scenarios generation

The current scenario and future scenarios which represent different feasible modifications to the network and urban area have to be generated. The generation of the current scenario requires current traffic counts and a base O-D matrix. Scenarios representing infrastructure modifications at the present time, besides require the modified network and the trips produced/attracted by the modified site (in case of a land use change). Scenarios representing a future time, additionally require the potential increase of vehicular movement for each sub-area. This increase is based on demographic, socioeconomic, vehicle fleet and urban spot growth information. The study area is divided in sub-areas; for each one, the following information is obtained and analyzed: *a*) Population density, population growth rate, and estimated future population; *b*) Current and estimated future vehicle fleet; *c*) Current and estimated future number of vehicles per capita; *d*) Current land use and "urban development plans" including detailed urban reserve zones; and *e)* Current urban spot and urban spot growth (including expected illegal growth).

The potential increase of vehicular movement, into each sub-area, is calculated with base on the estimated future number of vehicles in the sub-area, the sub-area type, and the above mentioned variables (Lozano *et al.*, 2002). Figure 1 shows the MZMC municipalities, classified in descending order according to their potential increase of vehicular movement. Two very different areas could have the same potential increase of vehicular movement, but this rate could be due to two different reasons. For example, a very poor zone in the outskirts of the metropolis could have the same rate as a high welfare zone near downtown, where population is diminishing and the number of cars per capita is high.

Multicriteria Analysis

To determine the impact of a road infrastructure modification is a difficult task; on one hand, it can contribute to improve the vehicular flow in certain zones, and on the other hand it can rebound on the environmental pollution, noise and vibrations, degradation of the urban image, among others. Some of these factors are not quantitative then, the problem becomes even more complex. For this scenarios assessment, we consider four criteria: congestion, emissions, urban image - environment, and cost.

Flow estimation and congestion impact

Current vehicular flow estimation on the network was obtained by means an user equilibrium model, using current traffic counts and a base O-D matrix. Flow estimation for future scenarios, also required the potential increase of vehicular movement (Lozano et al., 2005a).

The rate of estimated flow and capacity (r_i) and the number of kilometers with such rate (k_i), were used for obtaining a congestion indicator (j) by means Equation (1). The upper term considers the arcs whose flow is lower that their capacity, and gives a bigger value to near free flow arcs, while the lower term considers high congested arcs and gives a bigger value to arcs which have worst congestion and delay. Then, j is the rate between the kilometers with best flow and the kilometers with worst congestion and delay. Hence, if $j_A > j_B$, then scenario A is better than scenario B.

$$j = \left(\frac{\sum_{\forall r_i < 1} (1 - r_i) k_i^2}{- \sum_{\forall r_i > 1} (1 - r_i) k_i^2} \right) \qquad \text{(Eq. 1)}$$

Emissions impact

Emissions impact is a quantitative criterion which measures NOx, CO and HC tons, generated in the street network during the rush hour. Emissions, for each arc of the network, are estimated by using the estimated flow and speed for rush hour (result of the traffic equilibrium assignment) and Mobile 5.a (Lozano *et al.*, 2002).

Urban-environmental impact and cost

Due to the lack of information, urban image -environmental impact and cost are two qualitative criteria. They can take the following values: nil, low, medium, high y very high.

Multicriteria evaluation

In order to obtain a ranking of the feasible scenarios for each future time period, we use the multicriteria Electre IV Method, which compares alternatives by pairs, without assigning weights to the criteria.

Metropolitan Zone of Mexico City Problem

The Metropolitan Zone of Mexico City (MZMC) occupies an area of 70 kms per 60kms, and its main network (with at least six lanes) has over 15,000 arcs and 10,000 nodes. During the last two decades, the MZMC has had a disordered growth and almost null investment on the street network. Now, the MZMC has over 20 million habitants and near 4 million passenger cars, and huge congestion and environmental problems. Recently, the local government decided to build large infrastructure for the metropolitan street network. We applied the described approach for evaluating several scenarios and recommended a set of large modification on the street network. The government accepted many of our suggestions and built the first set of modifications (Lozano *et al.*, 2004).

Here, we present only the results for year 2008. The 2008 Base Scenario considers that the metropolis grew and the network was not modified since 2006 (the previous analysis period). Table 1 shows the values for each criterion and each 2008 scenario, and Table 2 shows the scenarios ranking, where the preferred scenario according the considered criteria is the called 2008PON-GC, which include the modification shown in Figure 2 (Lozano *et al.*, 2005b). Figure 3 and Figure 4 show the estimated flow and NOx emissions for this scenario.

Table 1. Criteria used for assessing 2008 Scenarios.

2008 Scenarios	*j*	Emissions decrease respect to 2008 Base Scenario			Cost	Urban-environmental impact
		HC	CO	NOX		
Base	2.42	0.00%	0.00%	0.00%	Nil	Nil
2PT	3.88	16.80%	16.03%	6.95%	High	High
2PVIAD	3.90	14.02%	14.41%	6.51%	Very High	Very high
CIRC-INT	2.63	1.44%	0.97%	-0.76%	Low	Low
E3OTE	2.79	0.70%	1.19%	0.25%	Medium	Low
LV-CM	2.92	11.63%	10.94%	3.39%	Very high	Very high
PON-GC	4.45	23.03%	22.68%	9.15%	High	Low

Table 2. Ranking of the 2008 Scenarios.

Rank	2008 Scenarios
1°	PON-GC
2°	2PT
3°	CIRC-INT
3°	Base
4°	E3OTE
4°	2PVIAD
5°	LV-CM

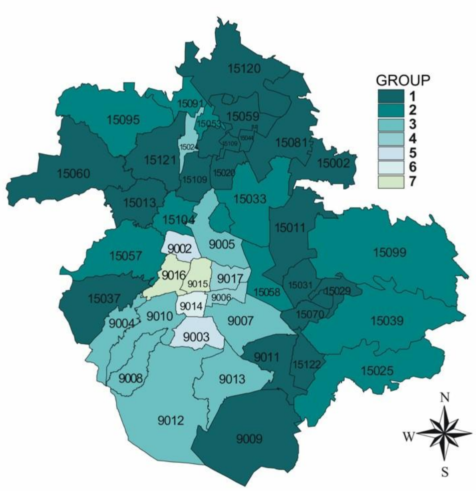


Figure 1. Mexico City municipalities, classified in descending order according to their potential increase of vehicular movement.

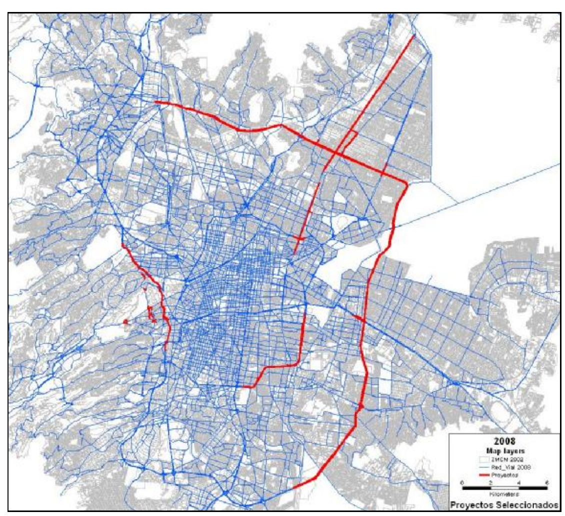
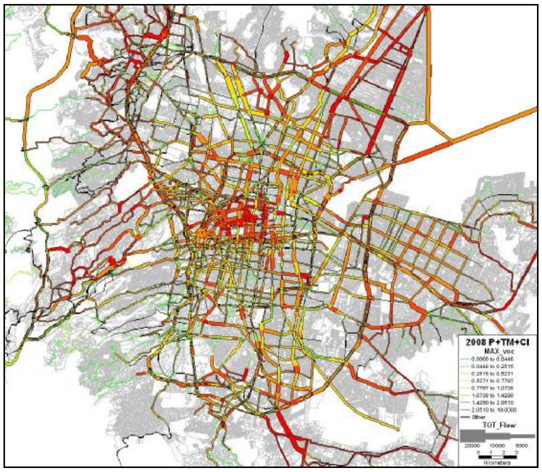


Figure 2. Set of modifications to the street network, for the preferred 2008 scenario.



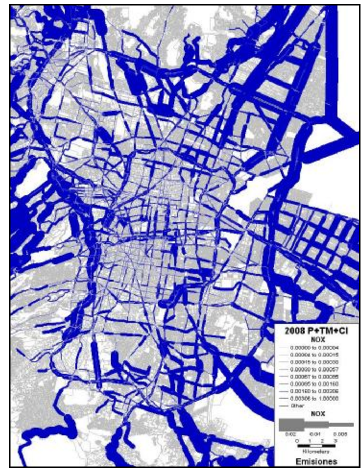


Figure 3. Estimated vehicular flow for the preferred 2008 scenario	Figure 4. Estimated NOx emissions for the preferred 2008 scenario

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