IMPACT OF NEW URBAN TOLL ROADS ON THE TRAFFIC OF THE CIUDAD UNIVERSITARIA (UNAM) IN MEXICO CITY

Angélica Lozano[1]

Francisco Granados[2]

Alejandro Guzmán[3]

Institute of Engeenering, Universidad Nacional Autónoma de México, México

{alozanoc, fgranadosv; lguzmanc}@iingen.unam.mx

ABSTRACT

We present an analysis of the impact of new urban toll roads on the traffic and local pollutant emissions of Ciudad-Universitaria (CU) zone within Mexico City. The analysis is based on user equilibrium traffic assignment for obtaining flows and speeds on arcs, and the Mobil5-Mexico City model for estimating emissions. The new toll roads are mainly located in the southern part of the City, just on the border of CU. We generated several scenarios for the current time (year 2012) and for the future; those scenarios include the new toll roads, complementary infrastructure (a set of bridges), and operational changes on traffic (flow direction changes for some arterials). The scenarios comparison results indicate that the toll roads have a positive impact in the short time, but it soon disappears; also show that operational changes work better than complementary infrastructure.

Keywords: Traffic Impact, Traffic Assignment, Transport Planning

INTRODUCTION

The following actions are considered for reducing congestion (Downs, 2004; Jayakrishan et al., 1998; Lozano et al., 2005; Zhang et al., 2011; Pozueta-Echavarri, 2008): a) the road network extension (new roads or improving of the existing ones); b) the public transportation service extension; c) the establishment of zone restrictions; d) the traffic management and control; e) the implementation of exclusive lanes for certain vehicles; f) the implementation of toll roads or zones; g) the elimination of street parking and road obstructions; h) the use of Intelligent Information Systems; and i) the planning of the city growing, based on territorial management (this is particularly important for cities of developing countries). Each one of these actions has advantages and disadvantages (except the actions h) and i), which just imply benefits), and its usefulness depends on the specific structure and characteristics of the city.

Hence, the development of urban toll roads is considered as a solution to traffic problems, sometimes without taking into account side effects. Usually studies on urban toll roads are focused on pricing and revenue, not on impacts (Kriger et al., 2006).

This paper analyzes the impact that a set of urban toll roads could have on traffic and emissions in Mexico City, specifically on the traffic around of the “Ciudad Universitaria” (CU Campus) of the “Universidad Nacional Autónoma de México” (UNAM).

CU campus is located in the southern part of Mexico City, covering an area of 2.7 square kilometres. It has over 107,000 students, 20,000 academics and 25,000 workers. In 2007, the CU campus was declared a World Heritage Site by the United Nations Educational, Scientific and Cultural Organization (UNESCO).

Currently in the southern and western parts of Mexico City, a set of urban toll highways are been constructed as second floor. These highways together have a length over 30 kilometres.

We analyse the impact of this set of urban toll highways on the traffic and emissions of the zone around CU campus. Several scenarios are generated, for the present time and for the future; these scenarios include modifications on the infrastructure as a set of bridges on an arterial road, and operational changes for traffic, as changes on flow direction for some arterials.

VEHICLE FLOW ESTIMATION

We estimate the flows on the arcs of the network by means of a multi-class user equilibrium traffic assignment model. This procedure required the road network, a set of base origin-destination matrixes (one for each user class) and traffic counts.

Several scenarios which consider the different road projects and traffic operation changes, for the current time and for a future short term, were generated and analyzed (Lozano et al, 2008).

Road Network

The road network covers the main and secondary roads in the whole Mexico City, and it is more detailed in the study area. It is composed of 150,000 arcs with the following attributes: name, flow direction, free-flow speed, capacity and calibrated parameters for the cost function.

The network inside the CU Campus is shown in Figure 1. The new urban toll roads are shown in Figure 2.

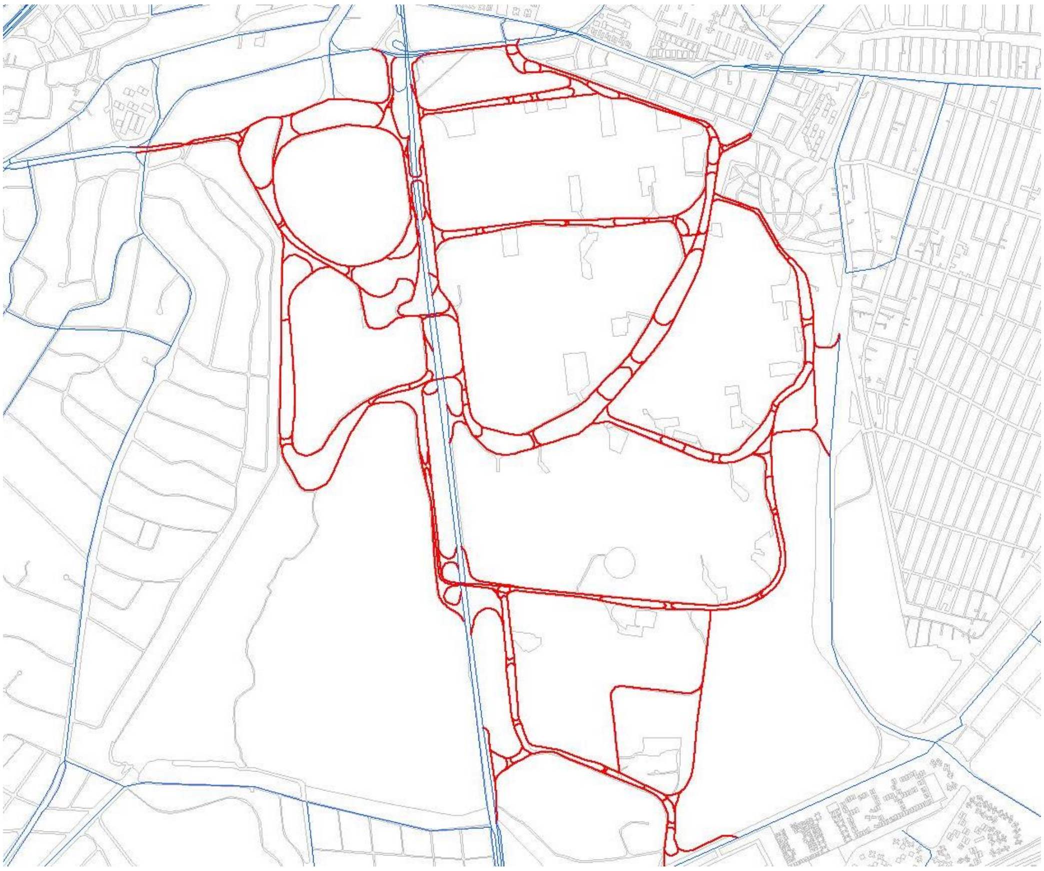

Figure 1 – Internal network of CU Campus

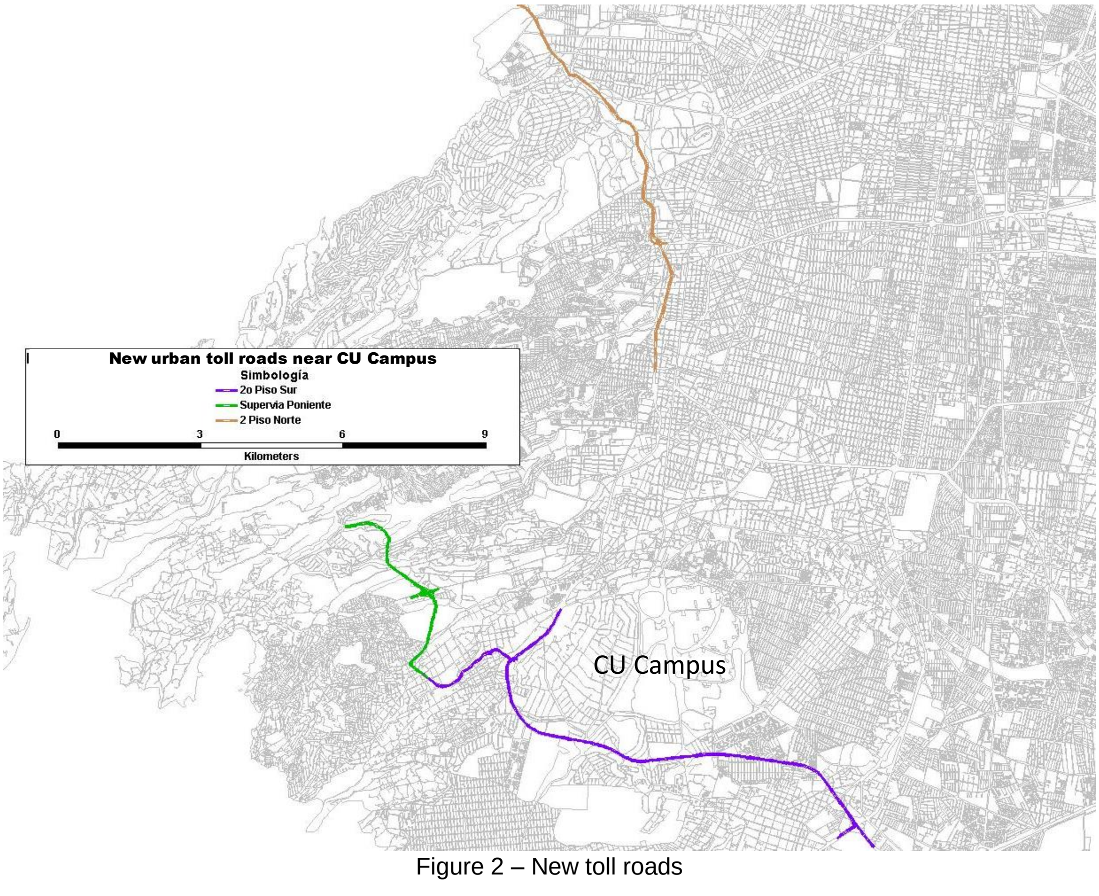

Figure 2 – New toll roads

Traffic Counts

Near 300 traffic counts are included in the model, their density is higher in the study zone. Additionally some traffic counts, located just in the exit/entrance points of the CU campus, were obtained and included. An example of traffic count in the study zone is shown in Figure 3. The rush hours for the study zone are presented in Table 1; these hours were established with base on traffic counts information and field work.

In addition, an extensive field work was performed in order to obtain speeds and travel times at rush hours on the main streets into the CU campus and in the whole study zone. This information is used for calibrating the cost function in the traffic assignment model.

Base O-D Matrices

The origin-destination matrices for Mexico City, one for each user class, were previously obtained from a survey. Each matrix includes over 1600 TAZ (Traffic Attraction Zones). The trips in the morning rush hour matrices are 1,319,505, and in the afternoon rush hour matrices are 932,687. The study zone is traversed by 43,996 trips (41% class 1, 21% class 2 and 38% class 3) at the morning rush hour, and 31,364 trips (32% class 1, 22% class 2 and 46% class 3) at the afternoon rush hour.

Originally, the CU campus had just one TAZ. Their trips (by car) for students and CU staff are shown in Figure 4. Then, we decided to divide the internal CU campus according the exit or entrance roads and ungroup its trips into five zones, so as the number of students and workers. One of the sub-zones covers the football stadium, whose parking is occupied by cars of students and visitors; its capacity is over 2,000 cars. These students and visitors can leave their car there for taking the free bus service which has 12 lines covering the whole campus.

Information of origins and destination out of the campus was originally grouped per municipality, which was not useful. Then we ungroup it by means the following process:

1. The following information was obtained per each homogeneous sub-area (AGEB) of each municipality: population in the age range corresponding to students, population in the age range corresponding to CU staff, land use and socio-economical level (INEGI, 2005, GDF, 2007).

2. The proportions of students going to a public university, according the socio-economical level was known. Hence we obtained for each AGEB, the probability of going to a public university and the estimated number of students going to a public university.

3. The proportion of students of UNAM among all the public universities in Mexico City was known. Hence we obtained for each AGEB, the probability of going to the UNAM and the estimated number of UNAM's students.

4. The proportion of UNAM students in the CU Campus was known. Hence we obtained for each AGEB, the probability of going to CU Campus and the estimated number of students going to CU Campus. They coincided with the number of students registered in the CU Campus.

5. According socio-economical level, we obtained the number of students going to CU Campus by car, and also their classification in the three socio-economical classes for the assignment model.

6. Then, according to traffic information, we obtained the number of students going to CU Campus by car at the morning rush hour and at the afternoon rush hour.

7. Finally, we related by means a gravity model, the origins and destinations.

A similar process was applied to trips of staff.

Figure 3 – Traffic counts at rush hour on the intersection Eje-10-Sur and Cerro-del-Agua

At the end, we obtained the following: At the morning rush hour (7:00am-8:00am), 2,832 cars arrive at or leave CU (the five zones), from them 88% arrive and 12% leave; 86% belong to students and 14% to workers. At the afternoon rush hour (6:30pm-7:30pm), 2,687 cars arrive at or leave CU (the five zones), from them 33% arrive and 67% leave; 73% belong to students and 26% to workers.

Almost 60% of CU trips have origin/destination in the stadium sub-zone. In the traffic assignment, which is presented below, these trips are sharing the internal network of CU campus with in-transit traffic.

Table I – Location and periods of traffic counts in the entrance/exit points of CU Campus

INTERSECTION	PERIOD
Eje 10 Sur & Cerro del Agua	06:00 – 09:00 18:00 – 21:00
Circuito Escolar Estadio Norte 1	06:00 – 09:00 18:00 – 21:00
Eje 10 Sur & Av. Universidad / Copilco	06:00 – 09:00 18:00 – 21:00
Circuito Escolar Estadio Norte 2	06:30 – 08:30 18:00 – 21:00
Circuito Escolar Estadio Oriente	06:30 – 08:30 18:00 – 20:00

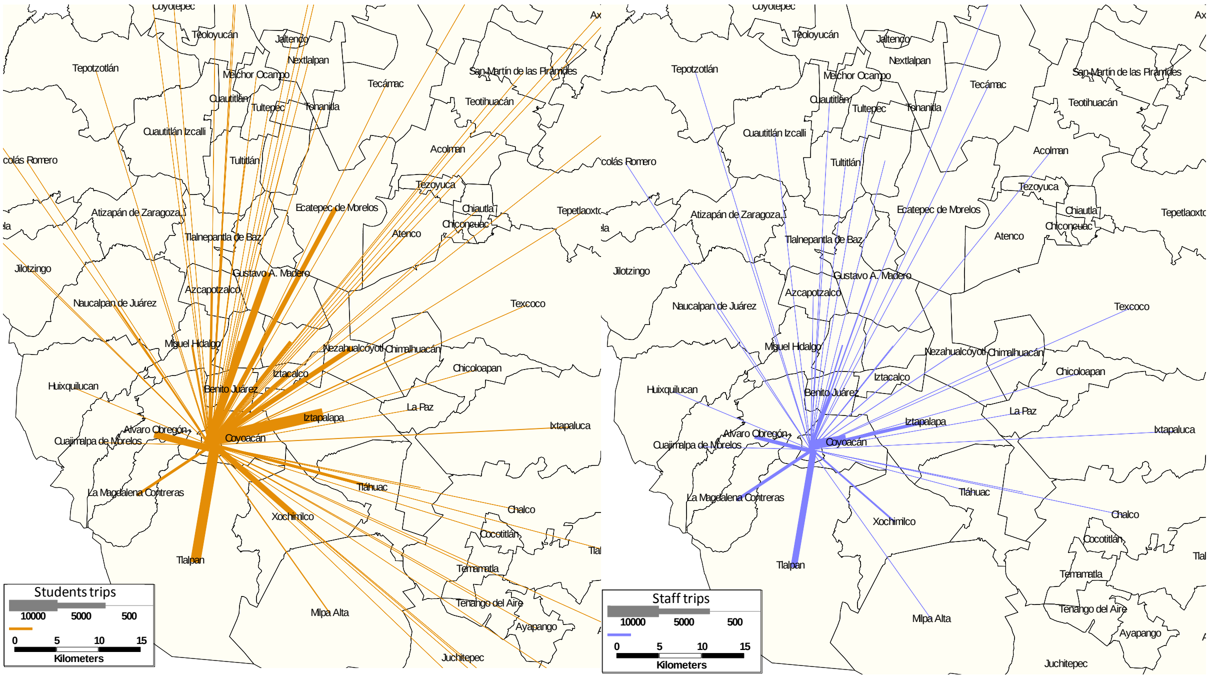

Figure 4 – Trips of students (yellow) and staff (blue) from CU Campus

Flow Estimation Procedure

The flow estimation was made by means of an algorithm for the User Equilibrium problem. User Equilibrium models assume that each user tries to minimize her travel time in the network, from her origin to her destination, without considering her actions effects on other users (Sheffi, 1985). A User Equilibrium Assignment model was chosen because it takes into account congestion impact on travel and route choice.

Previously to the algorithm application, a vehicles conversion was carried out to obtain passenger equivalent vehicles.

A user decides to use an urban toll road with base on: congestion in the alternative paths and the class (socio-economical level) he/she belongs. Then it is necessary to consider a multiclass model. We use a Multi-Class Traffic Assignment Model (Yang and Huang, 2004; Caliper Corporation, 2010), which take into account three classes of users grouped according their socio-economical level. A different time value was associated to each user class (Lam and Small, 2001; Ben-Akiva et al., 1993). These values were obtained by means of a survey.

The generalized cost function is shown in equation (1).

$$GC_{od}^{m} = \sum_{i \in A_{od}^{m}} \left\{ TV^{m}.VDF(t_a, c_a, x_a, \ldots) + FT_a^{m} \right\} \tag{1}$$

where,

GC_{od}^{m} = Generalized cost between origin o and destination d for class m

m = Class

a = Arc

od = Origin – destination pair

A_{od}^{m} = Set of arcs of the shortest path from o to d for class m

TV^{m} = Time value for class m

VDF = Delay due volume function

t_a = Free flow travel time on arc a

c_a = Capacity of arc a

x_a = Total volume on arc a

FT_a^{m} = Fix toll on arc a for class m

For the new urban toll roads, the fix toll is obtained by multiplication of length arc and toll per km.

The assignment procedure had two stages: the objective of the first stage was to obtain, for each user class, an O-D matrix from a set of seed O-D matrixes and traffic counts; and in the second stage, the estimated O-D matrixes were used to estimate vehicular flow on the arcs of the network for each scenario.

INDICATORS FOR COMPARISON

From the traffic assignment, the flow and speed on each arc of the network are obtained, and we also have the arcs' length and arc's capacity. All this information allows to use four indicators for the scenarios comparison: congestion, emissions (NOx, CO), travelled kilometres and travel time. Additional indicators can be included in the analysis, as the urban impact or social impact, but we had not useful information for included them.

Congestion index φ (Lozano et al., 2007) was used as an indicator of congestion, for each scenario. This index is shown in equation (2), where ρi is the ratio between estimated flow and capacity of link i (Volume over Capacity-VOC) and, κi is the number of kilometres at this rate. The upper term considers links whose flow is lower than their capacity, and gives a bigger value to near free-flow links, while lower term considers high congested arcs and gives a bigger value to links which have worst congestion and delay. Then, φ is the rate between the kilometres with best flow and the kilometres with worst congestion and delay. Hence, if $\varphi_A > \varphi_B$, scenario A is better than scenario B.

$$\varphi = \left(\frac{\sum_{\forall \rho_i < 1} (1-\rho_i) k_i^2}{-\sum_{\forall \rho_i > 1} (1-\rho_i) k_i^2} \right) \qquad (2)$$

Emissions factors (EF*p,v* in gr/km) were calculated by using Mobile5.0-Mexico City model and the results of the traffic assignment problem (vehicle flow and speed on each arc). Emissions of each pollutant were estimated using equation (3).

$$E_p = \sum_{i}^{n} KRV \times EF_{p,v} \qquad (3)$$

Where,

E_p =	Total emissions (grams) for pollutant *p*
KRV =	Total travelled kilometres on link *i*
EFp,v =	Emission factor (gr/km) for pollutant *p* and speed (km/hr) *v*, obtained by means of Mobile5.0-Mexico City model
n =	Number of links

Also, the number of travelled kilometres by all the vehicles, and the travel time for all the vehicles, were used for the scenarios comparison.

All the mentioned indicators were obtained just for the study zone.

SCENARIOS ANALYSIS

Scenarios description

For the present time (2012), the current scenario and several alternative scenarios which include changes in the road infrastructure and traffic operation were generated, for rush hours AM and PM. They are shown in Table 2, and described as follows:

- "Base Scenario" represents the current situation, without the urban toll roads.
- "Toll roads" means that urban toll roads are operating.
- "Bridges on Eje 10" means that a set of three bridges (two lanes in each direction) are located on the main road intersections on road Eje-10, which borders the northern part of the CU Campus.
- "Flow direction change on Universidad-Revolución (6)" represents that such two roads changed the flow direction producing just one direction arterials, as shown in Figure 5 and Figure 6, and that each arterial has six lanes.
- "Flow direction change on Universidad-Revolución (4)" represents that such two roads changed the flow direction producing just one direction arterials, as shown in Figure 5 and Figure 6, and that each arterial has four lanes because two lanes are bus dedicated.

Universidad and Revolución arterials currently have two flow directions. The proposal, included in some scenarios, is converting them into just one flow direction arterials.

Scenarios for the future time took into account the population increase and the land use changes in the study zone (Badoe and Miller, 2000; Herold et al., 2005). Hence, the future trips consider that territory had been modified. O-D matrices for future period were obtained with base on the current O-D matrices and the land-use changes in the study zone.

Table 2 – Scenarios

Year and Period	ID	Scenarios
2012 AM	1	Base AM
	3	Toll roads
	7	Toll roads and Bridges on Eje 10
	11	Toll roads, flow direction change on Universidad-Revolución (6)
	12	Toll roads, flow direction change on Universidad-Revolución (4)
	15	Toll roads and Bridges on Eje 10, flow direction change on Universidad-Revolución (6)
	16	Toll roads and Bridges on Eje 10, flow direction change on Universidad-Revolución (4)
2015 AM	5	Toll roads
	9	Toll roads and Bridges on Eje 10
	19	Toll roads, flow direction change on Universidad-Revolución (6)
	20	Toll roads, flow direction change on Universidad-Revolución (4)
	23	Toll roads and Bridges on Eje 10, flow direction change on Universidad-Revolución (6)
	24	Toll roads and Bridges on Eje 10, flow direction change on Universidad-Revolución (4)
2012 PM	2	Base
	4	Toll roads
	8	Toll roads and Bridges on Eje 10
	13	Toll roads, flow direction change on Universidad-Revolución (6)
	14	Toll roads, flow direction change on direction Universidad-Revolución (4)
	17	Toll roads and Bridges on Eje 10, flow direction change on Universidad-Revolución (6)
	18	Toll roads and Bridges on Eje 10, flow direction change on Universidad-Revolución (4)
2015 PM	6	Toll roads
	10	Toll roads and Bridges on Eje 10
	21	Toll roads, flow direction change on Universidad-Revolución (6)
	22	Toll roads, flow direction change on Universidad-Revolución (4)
	25	Toll roads and Bridges on Eje 10, flow direction change on Universidad-Revolución (6)
	26	Toll roads and Bridges on Eje 10, flow direction change on Universidad-Revolución (4)

Figure 5 – Arterials where the change of flow direction is proposed

Figure 6 – Arterials changing flow direction in the study zone

Scenarios Comparison

Scenarios were compared in order to understand the impact of toll roads and complementary infrastructure or traffic operation changes. The comparison uses the following indicators: NOx and CO emissions, congestion factor (1/φ), travelled kilometres by all vehicles, and travel time by all vehicles. These indicators were calculated just for the study zone.

In order to compare scenario *x* with respect to scenario *y*, the indicators' value of scenario *x* is divided by the indicators' value of scenario *y*, obtaining the proportion of variation of the indicators of scenario *x* with respect to the indicators of scenario *y*.

Table 3 shows the comparison between current (base) scenarios AM and PM, against scenarios with the urban toll roads for the current time and the future. Hence, scenarios 3 and 5 are compared respect to scenario 1, and scenarios 4 and 6 are compared respect to scenario 2. This comparison indicates that the urban toll roads reduce all the indicators in the short term, especially at the PM rush hour, but three years later all the indicators are worse than for the base scenario. Then, the impact of toll roads in the study zone is positive in the short term, but later their benefits disappear.

Tables 4, 5, 6 and 7 show the comparison between toll roads scenarios and scenarios with additional modifications, for rush hour AM and PM, and years 2012 and 2015.

The comparison of scenarios 7,11,12,15 and 16, respect to scenario 3, are shown in Table 4, and the comparison of scenarios 8,13,14,17 and 18, respect to scenario 4, are shown in Table 5. All these scenarios correspond to year 2012.

The comparison for year 2012 (Tables 4 and 5) indicates that the scenarios which include toll roads and additional modifications improve emissions, and some of them also improve congestion, travelled kilometres and travel time. The best scenario is the number 15 (AM), which includes bridges and changes of flow directions on arterials (six lanes). Scenarios with bridges on Eje-10 road don't improve indicators at AM period and get worse indicators at PM period; this fact is due to the traffic attracted from other paths to Eje-10 road.

The comparison of scenarios 9,19,20,23 and 24, respect to scenario 5, are shown in Table 6, and the comparison of scenarios 10,21,22,25 and 26, respect to scenario 6, are shown in Table 7. All these scenarios correspond to year 2015.

The comparison for year 2015 (Tables 6 and 7) indicates that all the scenarios with toll roads and additional modifications improve emissions, and some of them also improve congestion, travelled kilometres and travel time. The best scenarios are the number 23 and 24 (AM), which includes bridges and changes of flow directions on arterials (six and four lanes, respectively). Then, contribution of the set of bridges is not important (in the study zone). This fact is due to even though the Eje-10 road capacity is improved, a larger number of vehicles use it (many of them are attracted from other paths) producing congestion on the road segments where capacity was not improved.

Therefore, the best option is to change flow direction on the selected roads generating just one flow direction arterials. Scenarios for the six lanes case would be the best but given that bus routes cannot be changed to other arterials, scenarios for the four lanes case are suitable.

Figures 7 and 8 show the comparison between scenarios 03 (toll roads) and 12 (toll roads and flow direction change on Universidad-Revolución - four lanes) for AM period, and between scenarios 04 (toll roads) and 13 (toll roads and flow direction change on Universidad-Revolución - four lanes) for the PM period. Green arcs indicate that the operational changes (scenarios 12 or 13) produce less flow than the situation without them (scenarios 03 or 04); red arcs indicate the opposite (operational changes produce more flow that without them). From Figures 7 and 8, it is difficult understand what scenario is better than others; that is the reason why we use indicators for comparing scenarios (Table 3 to Table 7).

The indicators where obtained just for the study zone, then the mentioned results indicate the impacts on this zone. Perhaps some modifications (as the set of bridges) improve other zones out of the study zone. Hence the obtaining of indicators for a wider zone is recommended in order to decide what is the best for the whole city, not just what is the best for the CU Campus zone.

Table 3 – Comparison amongst current (base) scenarios and toll roads scenarios

ID	Current scenarios and scenarios without additional modifications	Emissions		Congestion factor (1/φ)	Travelled kilometres (km)	Travel time (hour)
		NOX (ton)	CO (ton)			
1	2012 AM - Base	1.000	1.000	1.000	1.000	1.000
3	2012 AM - Toll roads	0.960	0.937	0.852	0.946	0.904
5	2015 AM - Toll roads	1.076	1.168	1.240	1.056	1.315
2	2012 PM - Base	1.000	1.000	1.000	1.000	1.000
4	2012 PM - Toll roads	0.894	0.796	0.636	0.919	0.472
6	2015 PM - Toll roads	1.085	1.149	1.145	1.074	0.911

Table 4 – Comparison amongst toll roads scenario and scenarios with additional modifications, 2012 AM

ID	Emissions		Congestion factor (1/φ)	Travelled kilometres (km)	Travel time (hour)
	NOx (ton)	CO (ton)			
3	1	1	1	1	1
7	1.000	1.004	0.989	1.001	0.987
11	0.770	0.723	0.993	1.024	1.053
12	0.770	0.732	1.008	0.993	1.150
15	0.773	0.726	0.986	1.029	1.039
16	0.773	0.740	0.997	0.995	1.137

Table 5 – Comparison amongst toll roads scenario and scenarios with additional modifications, 2012 PM

ID	Emissions		Congestion factor (1/φ)	Travelled kilometres (km)	Travel time (hour)
	NOx (ton)	CO (ton)			
4	1	1	1	1	1
8	1.013	1.053	1.112	1.015	1.109
13	0.749	0.763	0.970	0.997	1.114
14	0.721	0.716	0.842	0.921	0.986
17	0.729	0.733	0.850	0.974	1.090
18	0.747	0.762	0.947	0.949	1.184

Table 6 – Comparison between urban toll roads scenario and scenarios with additional modifications, 2015 AM

ID	Emissions		Congestion factor (1/φ)	Travelled kilometres (km)	Travel time (hour)
	NOx (ton)	CO (ton)			
5	1	1	1	1	1
9	1.000	0.997	0.989	1.000	0.992
19	0.775	0.747	0.988	1.020	1.053
20	0.776	0.759	1.005	0.990	1.162
23	0.777	0.754	0.978	1.021	1.042
24	0.777	0.758	0.991	0.990	1.151

Table 7 – Comparison between toll roads scenario and scenarios with additional modifications, 2015 PM

ID	Emissions		Congestion factor (1/φ)	Travelled kilometres (km)	Travel time (hour)
	NOx (ton)	CO (ton)			
6	1	1	1	1	1
10	0.974	0.951	1.023	1.004	1.053
21	0.711	0.685	0.777	0.954	0.939
22	0.744	0.733	0.955	0.942	1.119
25	0.695	0.653	0.772	0.949	0.896
26	0.687	0.641	0.734	0.909	0.876

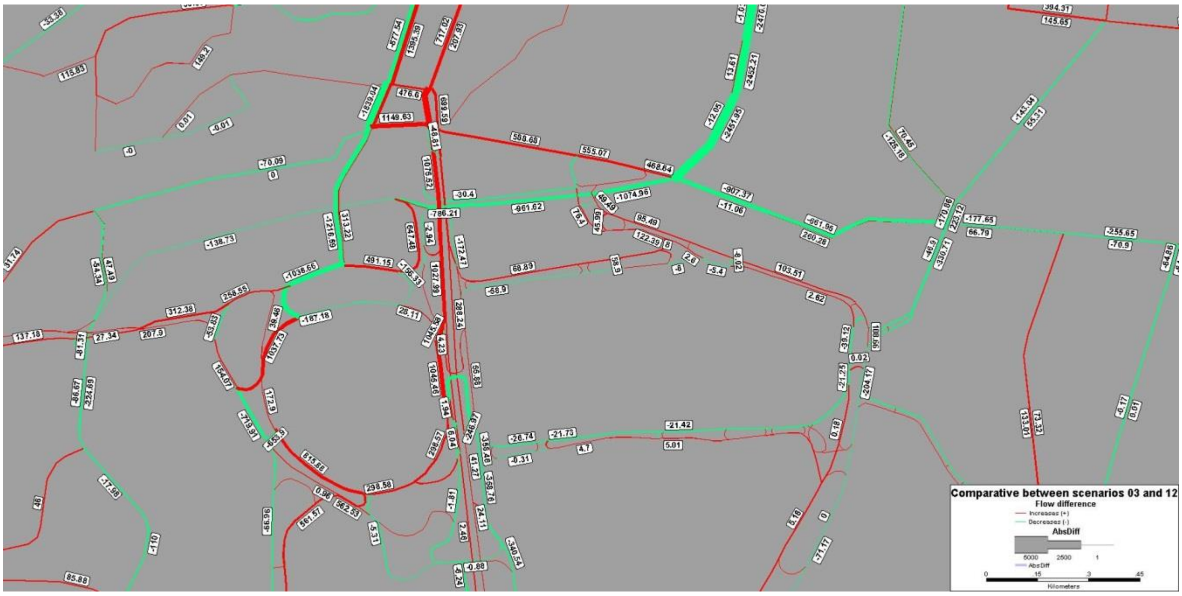

Figure 7 – Flow comparison between scenarios 3 and 12 (AM period); green arcs indicate that the flow is lower in scenario 12, and red arcs indicate the opposite

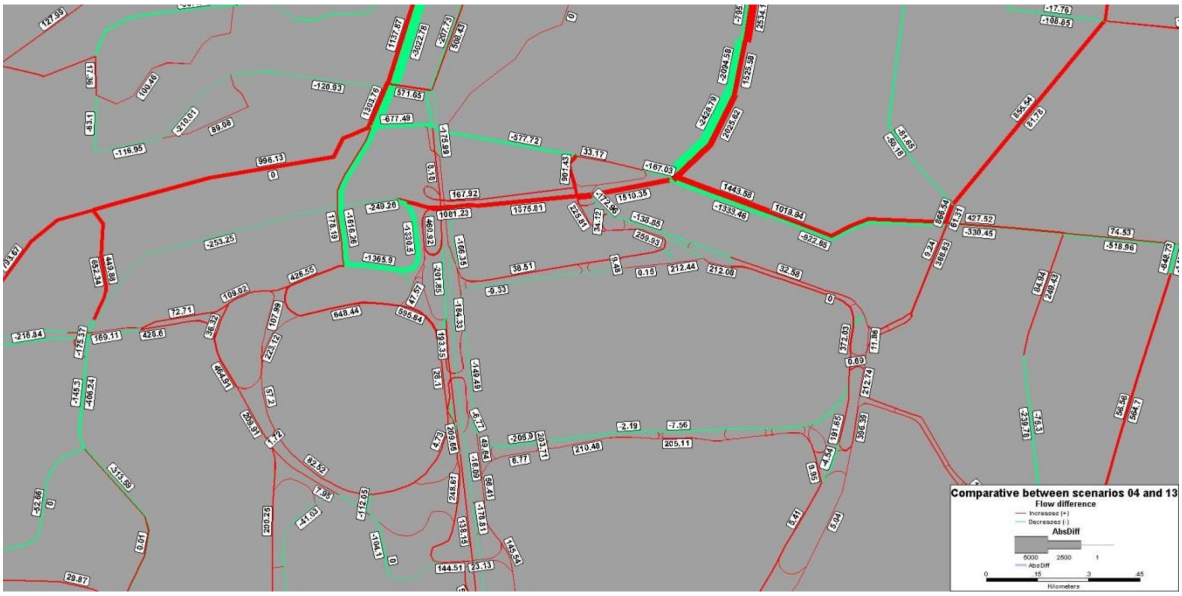

Figure 8 – Flow comparison between scenarios 4 and 13 (PM period); green arcs indicate that the flow is lower in scenario 13, and red arcs indicate the opposite

CONCLUSION

The analysis indicates that the construction of urban toll roads does not produce a consequent reduction on congestion and emissions problems on the medium and long terms in the CU Campus zone. The initial positive impact of the toll roads on the study zone disappears in few time, and when congestion increases outside CU Campus, its internal road network is used for in transit trips.

Operational changes as changing flow direction generating just one flow direction arterials, work better than a set of three bridges, because the bridges attract flow from other paths out of the study zone. The bridges could benefit the whole city but their impact is not significant on the CU Campus zone.

Building additional road infrastructure is more expensive and their benefits on traffic and emissions cannot be significant in the study zone.

The decision of what modifications produce on the road network must be based on indicators covering a wide zone; then the extension of the study zone is recommended.

The presented procedure for determining the impact of the new urban toll roads, and how to reduce it (a set of bridges and operational changes on roads), by means of the generation and comparison of scenarios, can be used for assessing any road infrastructure modification or road operational change in any city. The multiclass model is just required when toll roads are involved. In other case, a simple user equilibrium assignment can be used.

The usefulness of a network modification depends on the structure and characteristics of the urban road network and the city. Hence a traffic analysis, as the presented in this paper, must be done before implementing any operational change or building any road infrastructure.

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