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EX ANTE ASSESSMENT OF URBAN TRANSPORT FREIGHT POLICIES: AN APPLICATION IN MEXICO CITY

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1. ABSTRACT

This paper presents a methodology based on network traffic assignment and emission models to evaluate the effects and impacts, on traffic and local pollutant emissions (NOx and CO), from freight transport policies implemented in urban areas, with a study case application in the Metropolitan Zone of Mexico City -MZMC-.

The methodology is composed of nine steps: first step includes the processing of information on transport demand and supply. The second step comprises the interview's process to obtain carrier's reactions against the selected policies; interview's results are used for the definition of scenarios. In the third and fourth steps, O-D matrices and networks required for modeling each scenario are obtained. In the fifth step, pollutant emission factors for each vehicle type in the study zone are estimated.

In the sixth step, the traffic assignment model is solved and flows are estimated for each scenario (for base and alternative scenarios). With base on the traffic assignment model results, traffic assessment indicators are obtained in step seven, and emissions indicators are obtained in step eight, for each scenario. Finally in step nine, scenarios comparison is done in order to select the best scenarios and then do the policies assessment.

The proposed methodology was applied for the assessment of a time windows restrictions policy for heavy trucks on main entrance/exit roads in the MZMC. Results show that the indicators estimation for assessing impacts on traffic congestion and local emissions is adequate for assessing freight transport policies in large urban areas. The comparison of scenarios' indicators can support the decision making process on public policies, in similar urban contexts under certain assumptions.

Keywords: freight transport, emissions, traffic models

2. INTRODUCTION

In city logistics, business competitiveness demands deadlines and delivery quality. This has forced the reorganization of urban freight distribution, the development of better infrastructure and distribution services and, the increase of freight transportation in order to

deliver a greater number of orders to more destinations in shortest time, with some negative consequences on the urban transport system, where freight flows are part of this complex system sharing the road with passenger flows (Comi, 2005).

Urban freight transportation is a fundamental activity for economic development in urban areas, but it's operation generates a set of economic, social and environmental costs, which are not covered by transportation industry; these are the externalities, defined as the cost imposed on someone who is not directly involved in the freight movement, but is affected by it, such as traffic congestion, air pollution or noise. Whenever the external costs are not responsibility of private sector, or they are not incorporated into market economy, it will require government intervention to achieve social equality (Ogden, 1992). The government has to internalize these costs and protect the community from negative freight transport externalities through the development of public policies.

The implementation of measures on the freight system, based on policies proposed by the government are not enough by themselves to achieve the planned objectives; it is necessary to analyze and estimate ex ante the effects of such public policies on the comprehensive transportation system in order to evaluate their effectiveness, as part of planning process.

An essential tool for ex ante assessment process is the use of models, which allows the estimation of the impacts of the actions generated by public policies on the urban system. Different studies have shown that the best solutions for freight transport in urban areas come from the combination of a number of these measures (Filippi et al, 2010, Lyons et al, 2012). Models have to describe the behavior of main actors, incorporating activities such as freight movements, loading and unloading practices, traffic flows for freight and passengers vehicles and, as a result from modeling process obtaining congestion levels, pollutant emissions, logistics costs or noise impacts (Taniguchi, 2002).

The analysis of the effects and impacts of public policies on freight transport in large urban areas, based on networks transport models, has not been studied extensively; there are specific case studies for small and medium cities (Filippi et al, 2010; Buliung, 2008; Quak, 2006). Hence the proposed methodology and its application to the Metropolitan Zone of Mexico City –MZMC- could make important contributions to this type of analysis.

3. BACKGROUND

There are not universal public policies or measures to mitigate negative impacts from urban freight transportation, particularly in cities of developing countries where urban development planning or land use organization is emergent or sometimes nonexistent.

In European urban areas, freight transportation planning has focused on historic preservation or protection of residents against environmental pollution. Instead, in cities of developing countries, freight public policies are mainly concentrated in reduction of traffic congestion (G.I.Z, 2011). Public policies applied to freight transportation in urban areas of developing

countries are also reactive; they are implemented on response to an urgent or evident problem such as traffic congestion on certain roads or zones or, because of high levels of local pollutant emissions.

That is the case of Mexico City, where high volume of freight trucks travel on the main urban corridors and they share these corridors with passenger vehicles (cars and buses), contributing to high congestion and emissions at rush hours. Additionally, in the MZMC does not exist a comprehensive policy related to urban freight transportation, their impacts and externalities. There are punctual actions to mitigate evident problems such traffic congestion. These actions are usually restrictive and are not preceded by methodological ex ante assessment (Lyons et al, 2012).

The proposed methodology was developed from the analysis of a case study in the MZMC, taking in account recent decisions from local authorities: a) the possibility of time windows-TW- restrictions for heavy trucks on the main accesses/exits of the MZMC is considered in medium term, and b) different road improvement projects for other accesses/exits and internal freeways (north and east sections), in short and medium terms, are considered as complementary policies.

4. METHODOLOGY FOR ASSESSMENT OF PUBLIC POLICIES FOR URBAN FREIGHT TRANSPORT

The proposed methodology should be applied to urban areas with the following conditions:

• Large cities with complex traffic systems where roads are shared by passenger and freight vehicles.

• Urban areas where land use is not clearly defined: mix of residential, commercial and industrial land uses in the whole urban area.

• Urban areas where public infrastructure for logistics activities is incipient, restricted or nonexistent.

The proposed methodology is composed of nine steps; Figure 1 shows the summary of each step. The main aspects of each step are described in the following section.

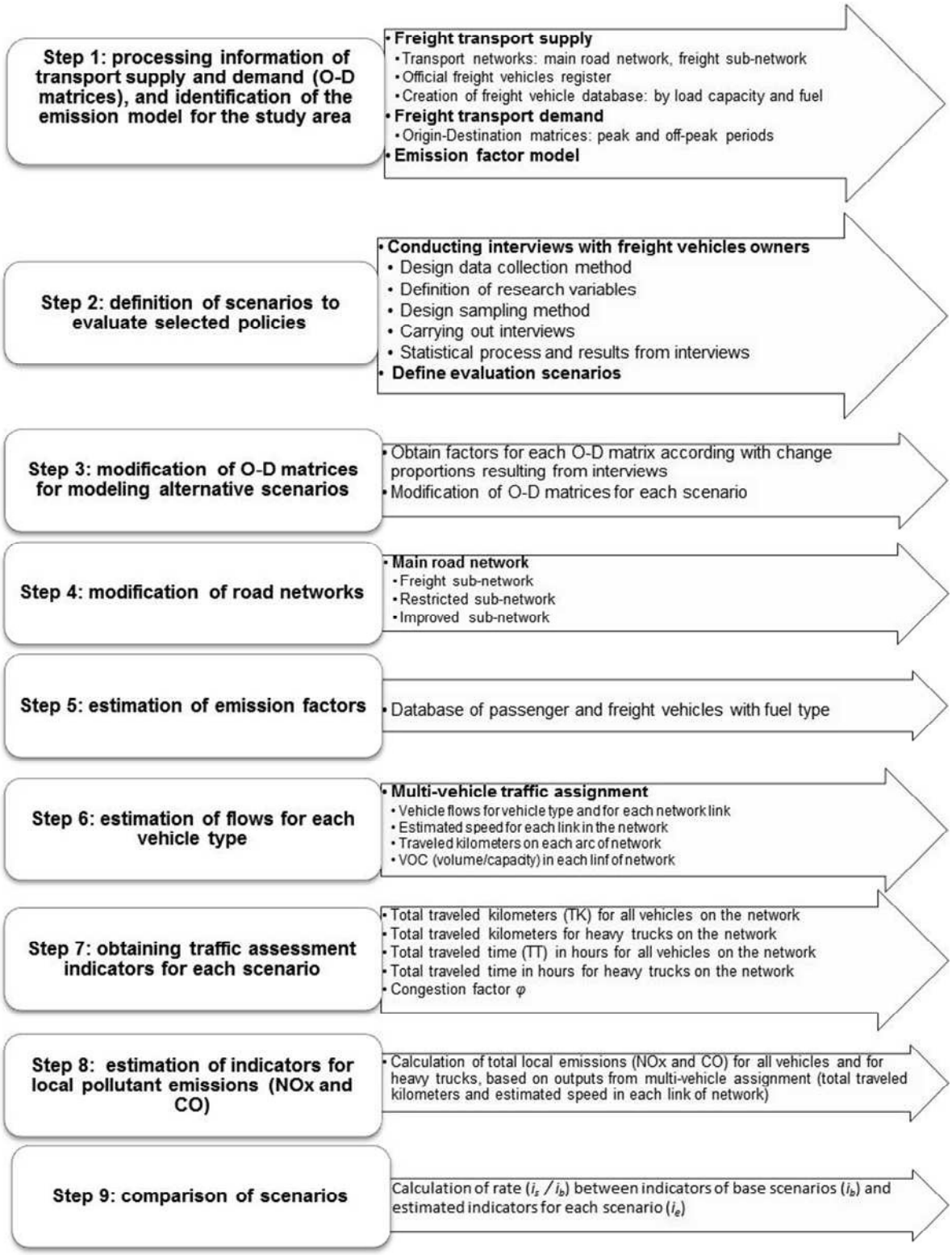

Figure 1. Methodology for assessment of public policies for urban freight transportation (Lyons L., 2012)

Step 1: processing information of transport supply and demand (O-D matrices), and identification of the emission model for the study area

The assessment of a selected freight transport policy requires the previous processing of the following urban freight transport information:

- A data base for freight vehicles: the creation of a database for freight vehicles, based on official register of commercial (freight) vehicles for base year, should include information about trucks companies' ownership, number of vehicles by company, classification of freight vehicles by load capacity, size and fuel type.
- A geographic road network: a traffic assignment model requires a main road network (for all type of vehicles, except heavy trucks) and a freight sub-network (where heavy trucks are permitted). All network arcs should have information of length, capacity (vehicles / lane / hour), cost function, free flow speed, travel time for free flow, and calibration parameters.
- A set of O-D base year matrices, one for each vehicle type, for peak and off-peak periods.
- Traffic counts for each vehicle type in both flow directions for a set of arcs, and for the same time periods.
- Characteristics of the emission model for the specific urban area.

Step 2: definition of scenarios to evaluate selected policies

The second step comprises the interview's process to obtain carrier's reactions against the selected policies; from these interviews the assessment scenarios are formulated.

One of the most important steps in this methodology is the knowledge of operational reactions from carriers in response to the policies; because these stakeholders will decide how to modify truck's operation in response to restrictions.

The interviewing process includes the design of data collection method, definition of dependent and independent variables (in which the interview's questions are focused), selection of sampling method, sampling designing, performing interviews and finally processing answers to obtain statistical results from interviews. The sampling design (including sample size and type) is dependent on the database of freight vehicles (described in Step 1): number of freight vehicles, number of freight vehicles per type, relation vehicles-owners, confidence level, permitted error, and standard deviation of the selected variables. This information is different for each city, so the sampling design features can vary from a city to another.

Based on the sampling results, the assessment scenarios for the policies can be defined and the requirements of changes in networks and matrices for each scenario should be established in order to continue to the next step.

Step 3: modification of O-D matrices for modeling alternative scenarios

The O-D matrices for scenarios defined in previous step are obtained by means the modifying of the base scenario O-D matrices (peak and off-peak period). Some scenarios just require the application of proportions which are obtained by interviews for each vehicle type (each cell of base matrix is affected by a factor corresponding to the proportions of operational changes). Other scenarios require the modifying of specific sets of cells, according changes on origins-destinations of sets of trips for certain vehicle types.

Step 4: modification of road networks

Each scenario also requires the adjustment of the road networks according to the scenario analyzed. For example, freight sub-network with restricted arcs, improved network, etc.

Step 5: estimation of emission factors

The emission factors for each type of vehicle and each speed are estimated. The source of information for emission factors models are the inventories of motor vehicle emissions that collect a wide range of data including: traveled vehicle kilometers, fuel consumption statistics, driving speeds, vehicle registration data, vehicle types and fuel characteristics, environmental characteristics, altitude, temperature, etc. Therefore emission factors for a city are just valid for such city. Emissions factors can vary very much from an urban area to another.

Step 6: estimation of flows for each vehicle type

Once defined matrices, networks and sub-networks for different scenarios, in step six are performed the traffic assignment process to estimate traffic flows on each arc of the network. Since estimated flows are required for each vehicle type, a multi-vehicle assignment model must be applied.

The main results obtained from the traffic assignment modeling for each scenario are the following:

• Traffic flow for each vehicle type, in each arc of the network.
• Traveled kilometers on each arc of the network, for each vehicle type.
• Estimated speed on each arc of the network.
• VOC (volume / capacity) for each arc of the network and for each flow direction.

Step 7: obtaining traffic assessment indicators for each scenario

Results from the multi-vehicle traffic assignment are used for obtaining the traffic indicators. The following indicators can be used for the scenarios comparison:

- Total traveled kilometers (TK) of all vehicles in the whole network. It is the sum of traveled kilometers by all types of vehicles (m) on each arc (i) of the network. TK

indicator is obtained with base on the length of arcs and flows on each arc for all types of vehicles.

- Total traveled kilometers corresponding to medium and large trucks on the freight sub-network. It is obtained in a similar way to the previous indicator, but just for heavy trucks.

- Total travel time (TT) in hours of all vehicles in the network. It is based on the estimated speed (s) on each arc (i), for all vehicle types (m).

- Travel time for medium and large trucks. It is calculated in the same way as the previous indicator but only for medium and large trucks.

- Congestion factor (φ) (Lozano et al, 2007). The rate of estimated flow and capacity (ρ_i) and the number of kilometers with such rate (κ_i), were used for obtaining a congestion index (φ) 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, φ is the rate between the kilometres with best flow and the kilometres with worst congestion and delay. Hence, if $\varphi_A > \varphi_B$, then scenario A is better than scenario B.

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

Step 8: estimation of indicators for local pollutant emissions (NOx and CO)

Results of the multi-vehicle traffic assignment process (step six) are used together with emission factors (step five) for obtaining total pollutant emissions for all vehicles in all arcs on the network, by using Equation 2 (Radian International, 1997).

For each scenario, the sum of emissions of all arcs is obtained, for all vehicles on the network and for heavy trucks. The sum of NOx and the sum of CO (local) emissions are obtained in a separated way.

$$E_p^c = \sum_i^n \sum_c^m KRV_{i,c} \times FE_{i,p,v,c} \qquad \text{Equation 2}$$

Where,

E_p^c = total emissions (grams) of pollutant p for vehicle type c
$KRV_{i,c}$ = traveled kilometers by vehicle type c on arc i
$FE_{i,p,s,c}$ = emission factor (gr/km) of pollutant p by vehicle type c traveling at speed s (km/hr), on arc i
n = total arcs on network
m = types of vehicle

Step 9: comparison of scenarios

The ratio (i_s / i_b) between estimated traffic and emissions indicators for base scenarios (i_b) and for each alternative scenario (i_s) are calculated, both for rush hour and off peak hour, in order to compare scenarios. A numerical scale should be established according to the obtained ratios to facilitate the comparison amongst scenarios, and then facilitate the selection of the best scenario and the assessment of policies.

5. APPLYING THE METHODOLOGY TO METROPOLITAN ZONE OF MEXICO CITY

The Metropolitan Zone of Mexico City is the most important center of economic and social activities in Mexico; it has a population near 20 million inhabitants, 17.9% of country total population. The urban area is about 2,504 km^2 and is composed of the Federal District (16 municipalities) and 59 municipalities of Mexico State and one of Hidalgo State.

Daily, there are 22 million passenger trips in public transport and private cars. At the morning rush hour there are over 1.6 million vehicle trips in cars and trucks. Nearly 21% of these trips are truck trips: 9% mini trucks, 4% small trucks, 6% medium trucks and 2% large trucks.

Recently, due to the high traffic congestion on main access corridors of the MZMC, local authorities have begun to implement TW (time windows) restrictions to large and medium trucks (over 3.5 capacity tons.) at rush hours on main road accesses/exists. The access/exist corridors are part of the freight transportation network and supply system of Mexico City, and connect the MZMC with the central states. Trucks and passenger vehicles (cars and buses) share lanes on those corridors.

The methodology described above was applied to evaluate impacts of this TW policy on traffic and local emissions in the MZMC. The example presented below corresponds to four of the fifteen scenarios evaluated in the entire research; the assessment results for the fifteen scenarios are presented in Lyons et al., (2013). The main results of the application of the proposed methodology to a case study are described below.

Step 1: processing information of transport supply, demand; and emission models for MZMC

- Transport supply information was obtained from the MZMC official register commercial vehicle data. Table 1 presents a summary of information obtained from the freight vehicles database generated for this study as resulting of processing official register data.

- For demand information, base O-D matrices used in this research were obtained from the study of travel demand for freight transport in the MZMC (Lozano et al, 2006), with projections to year 2010. The mentioned study defined 1,924 traffic attraction zones. Table 2 shows total number of trips by vehicle type in MZMC.

- The main urban network has near 5,400 km (15,000 arcs), where 2,000 km (4,500 arcs) are part of the freight sub-network (see Figure 2). Each arc has information on length, capacity (vehicles / lane / hour), cost function, free flow speed, travel time for free flow and calibration parameters.

Table 1 – Freight Vehicle Classification – MZMC –

Vehicle Size	%	Number of Vehicles MZMC Year 2010
Mini trucks	45.2	308,200
Small trucks	21.3	144,953
Medium trucks	22.0	150,044
Large trucks	11.5	78,139
Total	100	681,336

Table 2– O-D trips in MZMC by vehicle type

Vehicle Type	O-D Base Matrix Peak Morning Hour (Vehicle trips)
Passenger (private cars)	1,334,700
Mini trucks	155,009
Small trucks	63,734
Medium trucks	99,880
Large trucks	32,140

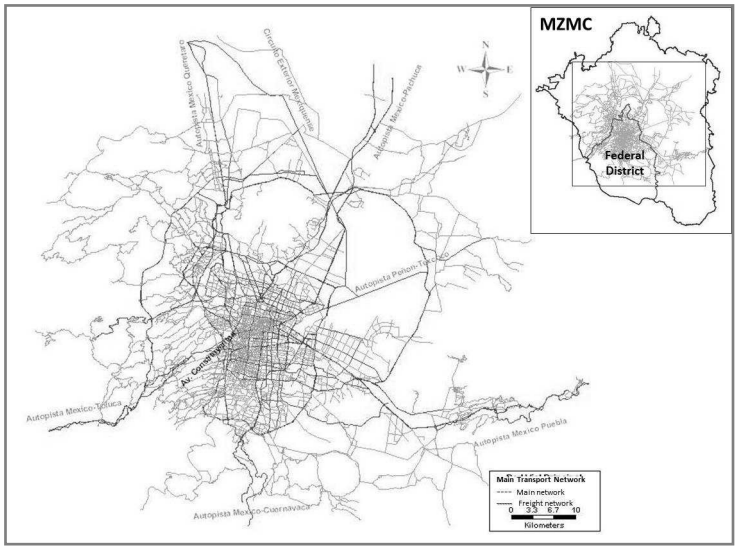

Figure 2– Transport Networks MZMC (Lyons et al, 2012)

- The model *Mobile5-Mexico City* was used to estimate emission factors of NO_x and CO for the different types of vehicles defined in this research. The main reason to choose version 5 of *Mobile-Mexico* is that this version allows to an expert user estimates emission factors with speed outputs from the assignment model. In Figure 4 (step 5) are presented the graphical results of local (NOx and CO) emission factors for MZMC.

Step 2: definition of scenarios to evaluate TW restrictions in MZMC

Carrier's reactions to the TW restriction policy were obtained by means of random interviews to operational and logistics managers of companies with large fleets.

Sample size for interviews was obtained based on the MZMC official register commercial vehicle data (obtained in Step 1), where 1.22% vehicle owners have 38.27% commercial vehicles (there are high concentration of freight vehicular property in MZMC). Stratification by size was used together with cluster sampling technique, considering companies and owners as primary population unit and number of vehicles per size as secondary population unit. As a result of cluster sampling design, ten operational and logistics managers which are owners of 12,350 different size trucks, from randomly selected companies were interviewed. In that cluster sample, the required number of vehicles for each vehicle size was covered by the selected companies.

Based on trucks owner's responses, four possible operational options from carriers to TW restrictions were identified: 1) 5% of large and medium trucks would be replaced by small trucks in order to avoid restrictions; 2) 35% of large and medium trucks that would change operational schedules (to off-peak operations), 3) 60% of heavy trucks that would change paths (including on the improved network arcs) and 4) 2% of trucks that would use truck's facilities (consolidation centers) located in the border of the MZMC (where smaller vehicles would continue the trip to the large and medium trucks' original destinations).

The result for each possible operational option is not just a percentage; it is an interval with 90% confidence level. In this example, for simplicity we consider just the medium values for the scenarios definition. It would be very good to consider also the extreme values of the intervals and generate a sensitivity analysis. It was not included in this paper due that it implies the analysis of a number of scenarios.

For our example, additional to base peak and off-peak scenarios, six assessment scenarios for TW restrictions and road improvements were defined. Considering that in some scenarios, a proportion of heavy vehicles changes operational schedules to off-peak hour, it was necessary to define additional scenarios for morning hours (peak + off peak hours) in order to know the impacts of policies in whole period.

Results from interviews indicated the required changes in networks and matrices, for each scenario. The selected scenarios are described below:

1. Scenario 4.2A: trucks are prohibited on main accesses of MZMC at morning rush hour and 60% of heavy trucks change paths, 5% are substituted by small vehicles, 33% change their trips to off-peak time and 2% use consolidation centers where heavy trucks change to small trucks and continue their trips (new O-D freight vehicle matrix was used). Freeways and some roads are improved.

2. Scenario 4.2B: morning off-peak time, freeways and some roads are improved. 33% of heavy trucks, which changed travel time, are traveling during the morning off-peak time on the improved network.

3. Scenario 4.3A: trucks are forbidden on accesses/exits at morning rush hour and 61% of heavy trucks change paths, 5% are substituted by small vehicles and 34% change their trips to off-peak time. Freeways and some roads are improved. Consolidation centers were not considered.

4. Scenario 4.3B: morning off-peak time, freeways and some roads are improved. 34% of heavy trucks, which changed travel time, are traveling during the morning off-peak time on the improved network.

5. Scenario 4.2A + 4.2B represents total morning period for scenarios 4.2.

6. Scenario 4.3A + 4.3B represents total morning period for scenarios 4.3.

Step 3: modification of O-D matrices for the MZMC case study

The described six scenarios consider simultaneously changes in vehicle size, hours of operation and routes, and also the use of consolidation centers; these are the main reactions from heavy vehicles caused by TW restrictions.

For example, to modify O-D matrices for scenarios 4.3A and 4.3B, each cell of base O-D matrices (peak and off-peak) was affected for a factor obtained from proportions obtained from interviews, as described in Equation 3 and Equation 4:

$$PM_{4.3A,RH} = PM_{b,RH}$$
$$NM_{4.3A,RH} = NM_{b,RH}$$
$$SM_{4.3A,RH} = SM_{b,RH} + 0.2112 \text{ x } MM_{b,RH} + 0.24905 \text{ x } LM4_{b,RH}$$
$$MM_{4.3A,RH} = MM_{b,RH} - 0.23 \text{ x } MM_{b,RH} - 0.033 \text{ x } MM_{b,RH} = 0.7373\ MM_{b,RH}$$
$$LM4_{4.3A,RH} = LM_{b,RH} - 0.11 \text{ x } LM_{b,RH} - 0.017\ LM_{b,RH} = 0.863\ LM_{b,RH}$$

Equation 3

$$PM_{4.3B,OP} = MP_{b,OP}$$
$$NM_{4.3B,OP} = NM_{b,OP}$$
$$SM_{4.3B,OP} = SM_{b,OP}$$
$$MM_{4.3B,OP} = MM_{b,OP} + 0.23 \text{ x } MM_{b,RH}$$
$$LM_{4.3B,OP} = LM_{b,OP} + 0.11 \text{ x } LM_{b,RH}$$

Equation 4

Where,

$PM_{i,j}$ = O-D passenger vehicles matrix for Scenario i at period j

$NM_{i,j}$ = O-D mini trucks matrix for Scenario i at period j

$SM_{i,j}$= O-D small trucks matrix for Scenario i at period j

$MM_{i,j}$ = O-D medium trucks matrix for Scenario i at period j

$LM_{i,j}$= O-D large trucks matrix for Scenario i at period j

j= RH (rush hour) or OP (off peak hour)

If $i=b$, scenario i is the base scenario

In scenarios 4.2A and 4.2B, the use of consolidation centers generates trip redistribution in the study area, because heavy and small trucks arrive from different origins to a consolidation center located outside the restricted areas, making this center a new origin or destination zone for these truck trips, which must be reflected in the O-D matrix. Taking into account those changes in trip distribution, a new O-D matrix was generated and the results are presented in Table 3.

Step 4: modification of road networks for the MZMC case study

The original freight sub-network was modified, for those arcs where trucks are prohibited at TW restriction (see Figure 3). These arcs are the main five road accesses to MZMC (nearly 100 Km): the México-Querétaro Highway (43.9 Km), the México-Pachuca Highway (14 Km), the México-Puebla Highway (16 Km), the México-Cuernavaca Highway (13.8 Km, including a section of Insurgentes South Avenue), and the Constituyentes Avenue (12.8 km).

The improved road network considers the capacity increase on some other access/exits roads to MZMC (i.e. bridges on Los Reyes-Texcoco road, new sections on the South Mexiquense Highway, second floor on the Periférico Oriente toll road), as shown in Figure 3. Those roads are concentrated on the east-northern part of the MZMC, since in other accesses there was not possibility to build large road improvements.

Step 5: estimation of emission factors for MZMC

As mentioned in step one, emission factors for NOx and CO for vehicle type were obtained by means Mobile5-MexicoCity, for speeds between 2.5 and 105 Km/hour. In Figure 4 are presented these factors in gr/km.

Table 3– New O-D matrix for MZMC by vehicle type

Vehicle Type	O-D Base Matrix Peak Morning Hour (Vehicle trips)	O-D Matrix Consolidation Centers	Change (%)
Passenger (private cars)	1,334,700	1,334,700	0%
Mini trucks	155,009	155,009	0%
Small trucks	63,734	102,869	+61%
Medium trucks	99,880	77,166	-23%
Large trucks	32,140	29,838	-7%

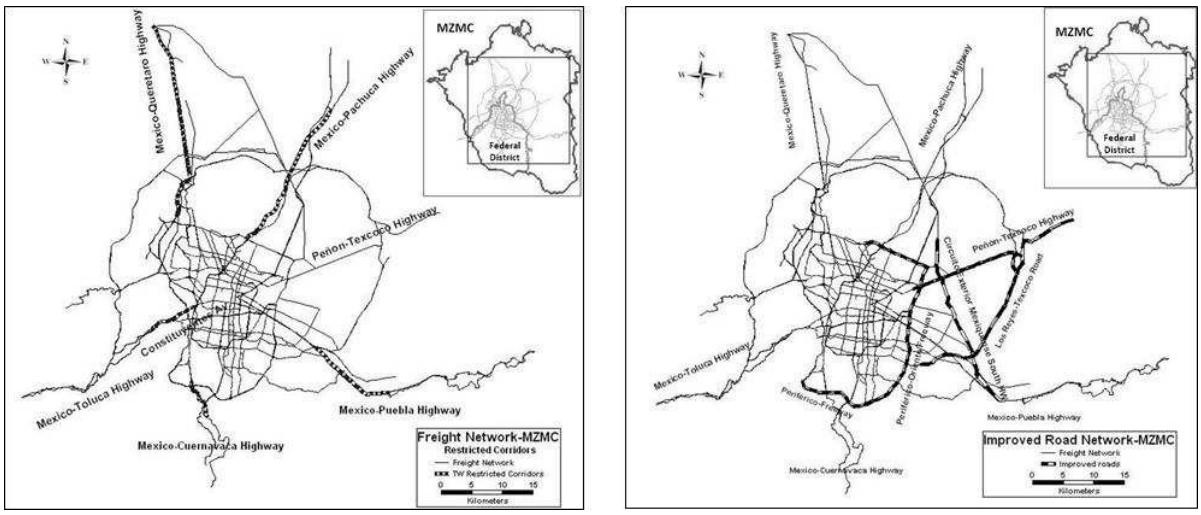

Figure 3– Restricted and Improved Networks - MZMC (Lyons et al, 2012)

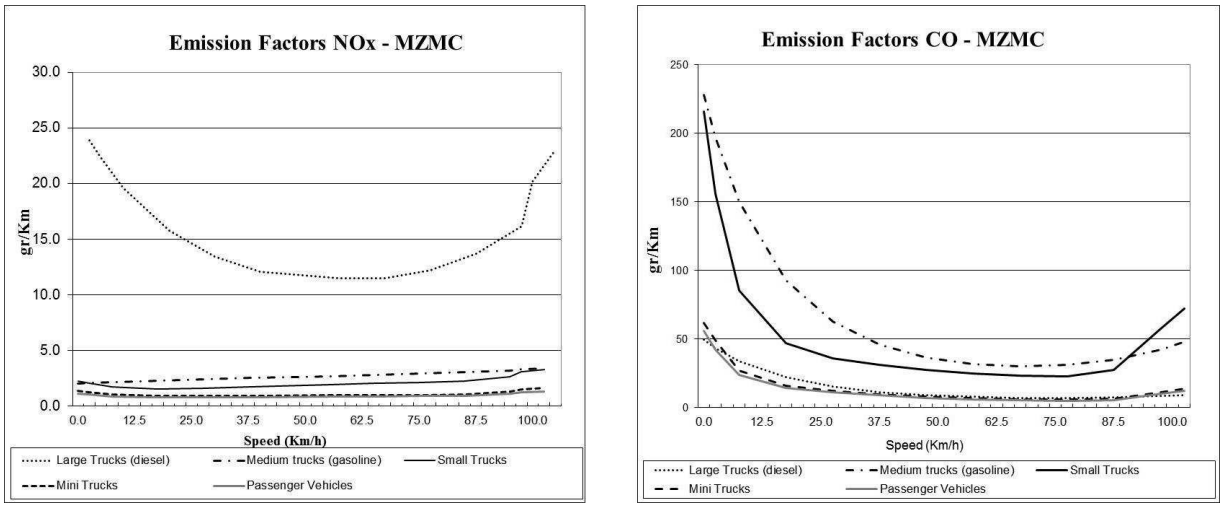

Figure 4– Emissions factors for MZMC (Lyons L., 2012)

Step 6: estimation flows for vehicle type

A User Equilibrium Multi-Vehicle Traffic Assignment Model, with an O-D matrix for each vehicle type and each operational change option, was used for estimating vehicle flow, speed, travel time and traveled kilometers, on all arcs for each vehicle type. Figure 5 shows inputs and outputs from the multi-vehicle traffic assignment model, applied to each scenario of the case study.

Step 7: obtaining traffic assessment indicators for the selected scenarios

Traffic indicators were obtained with base on the outputs from the multi-vehicle traffic assignment model: congestion factor (φ), total traveled kilometers (TK) for all vehicles and for heavy trucks; and total traveled time (TT) in hours, for total vehicles and for heavy trucks. The results for the selected scenarios are presented in Table 4.

Step 8: estimation of local pollutant emissions (NOx and CO)

Estimated speed and estimated traveled kilometers (obtained from the multi-vehicle traffic assignment model) were used to estimate total pollutant emissions for all vehicles and for heavy trucks on the network by means of Equation 2. The total local emissions of NOx and CO for the selected scenarios are presented in Table 5.

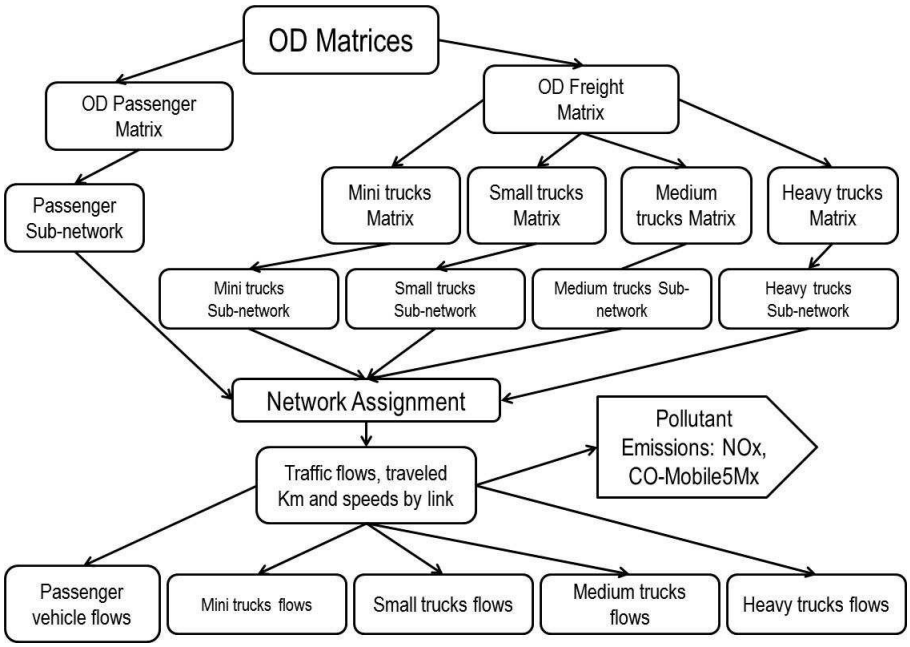

Figure 5– Inputs and outputs from the Multi-vehicle Traffic Assignment Model (Lyons L., 2012)

Table 4– Traffic Indicators

Scenarios	1/Congestion Index (φ)	Total Traveled Kilometers-TK		Total Traveled Time-TT (hours)	
		Total	Trucks	Total	Trucks
Scenario 1.1A	3,81	19.963.326	3.979.936	22.248.634	5.756.533
Scenario 4.2A	3,52	19.939.503	2.227.836	19.388.789	2.815.997
Scenario 4.3A	2,78	18.982.143	2.347.410	16.113.424	2.796.837
Scenario 1.1B	2,26	18.015.230	3.938.180	18.168.144	5.452.182
Scenario 4.2B	2,71	19.004.517	3.699.057	19.803.117	5.161.320
Scenario 4.3B	2,30	17.642.419	3.895.516	12.344.159	4.050.691
1.1A+1.1B	3,01	37.978.556	7.918.117	40.416.778	11.208.715
4.2A+4.2B	3,11	38.944.020	5.926.894	39.191.906	7.977.317
4.3A+4.3B	2,52	36.624.562	6.242.926	28.457.582	6.847.528

Table 5– Local Pollutant Emission

Scenarios	Total Local Emissions (tons)		Truck´s Local Emissions (tons)	
	NOx	CO	NOx	CO
Scenario 1.1A	39,80	752,69	29,17	185,59
Scenario 4.2A	29,74	741,53	18,44	119,23
Scenario 4.3A	29,30	610,20	19,34	125,99
Scenario 1.1B	38,70	785,84	28,37	180,70
Scenario 4.2B	37,93	919,03	26,29	176,28
Scenario 4.3B	35,74	651,31	26,42	174,16
1.1A+1.1B	78,50	1538,53	57,53	366,29
4.2A+4.2B	67,67	1660,56	44,73	295,51
4.3A+4.3B	65,03	1261,51	45,76	300,16

Table 6– Comparison of scenarios, for TW on road accesses policy

Scenarios	Total Local Emissions		Trucks Local Emissions		1/Congestion Index	Total Traveled Kilometers-TK		Total Traveled Times-TT	
	NOx	CO	NOx	CO		Total	Trucks	Total	Trucks
Scenario 1.1A	1	1	1	1	1	1	1	1	1
Scenario 4.2A	0,75	0,99	0,63	0,64	0,92	1,00	0,56	0,87	0,49
Scenario 4.3A	0,74	0,81	0,66	0,68	0,73	0,95	0,59	0,72	0,49
Scenario 1.1B	1	1	1	1	1	1	1	1	1
Scenario 4.2B	0,98	1,17	0,93	0,98	1,20	1,05	0,94	1,09	0,95
Scenario 4.3B	0,92	0,83	0,93	0,96	1,02	0,98	0,99	0,68	0,74
1.1A+1.1B	1	1	1	1	1	1	1	1	1
4.2A+4.2B	0,86	1,08	0,78	0,81	1,03	1,03	0,75	0,97	0,71
4.3A+4.3B	0,83	0,82	0,80	0,82	0,84	0,96	0,79	0,70	0,61

Much Better	Better	Idem	Worse	Much Worse

Step 9: comparison of selected scenarios

Finally in this step, to compare scenarios and perform policies assessment, the ratio between estimated traffic and emissions values for base scenarios and for each alternative scenario were calculated, for rush hour, off peak hour and morning period. These ratios are shown in Table 6.

6. DISCUSSION OF RESULTS FROM POLICIES ASSESSMENT IN MZMC

The indicators obtained from the application of the proposed methodology, for the assessment the policy of TW restrictions for heavy trucks on main accesses at rush hour in MZMC, and improved network as a complementary policy, shown the following:

1. In scenario 4.2, where there are included all operational options from carriers, truck's emissions in the morning period (4.2A +4.2 B) decrease 22% for NOx and 19% for CO, as well as TK decreases 25% and TT 29% for heavy trucks, compared with base morning period (1.1A + 1.1B).

   Indicators of morning scenario for all vehicles are similar to those of the base morning scenario, except total NOx emissions which decreases 14%.

2. For the total morning period of scenario 4.3 (4.3A + 4.3B), all indicators are better than those for the base scenario (scenario 1.1A + 1.1B), with lower emissions of NOx (20%) and CO (18%) for heavy trucks, and lower traveled kilometers (21%) and traveled time (39%) for these vehicles.

Congestion indicator for this scenario also decreases 16%, while emissions of NOx and CO decrease 17% and 18%, respectively for all vehicles. The traveled kilometers and traveled times for all vehicles in the network decrease 4% and 30% respectively.

3. From the comparison of indicators of the total morning period for both scenarios (4.2A+4.2B vs. 4.3A+4.3 B), where the difference is that scenarios 4.3 do not consider consolidation centers, it was estimated that indicators for total morning period of scenarios 4.3 are better than for scenarios 4.2: 2% and 1% lower NOx and CO emissions for trucks, respectively; 4% and 10% lower TK and TT for trucks, respectively; and 19% lower congestion of all vehicles.

   Scenario 4.3A+4.3B also improves TK and TT for all vehicles on the network, 7% and 27% respectively, and NOx and CO emissions, 3% and 26% respectively.

The comparison of these two groups of scenarios (all operational options with and without consolidation centers, i.e. scenarios 4.2 y 4.3) shows that better indicators are obtained for the scenarios without consolidation centers. These results reflect that consolidation centers contribute to high congestion around them, due to the concentration of heavy trucks flows (arriving to the consolidation center) and small truck flows (departing from the consolidation center after truck´s change). These additional flows on access roads to consolidation centers and its surrounding area, increase congestion on near roads, and affect negatively total network performance. This problem is also due to the lack of adequate road infrastructure in the sites around the available plots for the location of the consolidation centers.

7. CONCLUSIONS

The results from methodology application to the case study show that it is adequate to estimate indicators for assessing impacts on traffic congestion and local emissions in large urban areas and then for assessing policies related to urban freight transport. This methodology and its indicators for each scenario can be a support for decision making process on public policies, in similar urban contexts under certain assumptions.

The proposed methodology allows including different stakeholders: local authorities, carriers and other users of the transport system not involved with freight activities, in the impact analysis of urban freight transportation policies. The traffic assignment model included in this methodology, facilitates the analysis of freight policies for large urban areas, and supports planning process.

The assessment of this case study (time windows restrictions for heavy trucks on main entrance/exit roads in the Metropolitan Zone of Mexico City) simultaneous included different changes on truck's paths and truck's size, and changes of operational schedules to off-peak hour, producing a realistic situation. The best results on traffic indicators (total traveled kilometers and total travel times) and local pollutant emissions were obtained for the scenario without consolidation centers. If there is not adequate road infrastructure near consolidation centers, they can contribute to increase congestion and should be not considered as an operational option.

It would be important for the case study to do a sensitivity analysis on the percentage related to possible operational options from carriers to TW restrictions, It was not included in this paper due that it implies the analysis of a number of scenarios, and exceeds the scope of this paper whose objective is to present a methodology for assessing policies and an application example.

The presented methodology can be used for assessing other groups of scenarios for the case study, or other policies on heavy trucks in Mexico City, and also can be applied to assess heavy truck policies in other large cities.

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