A PROPOSAL FOR OPTIMIZING URBAN MOBILITY IN MEXICO CITY BASED ON THE PUBLIC TRANSPORT NETWORK

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ABSTRACT

At global level, last year Mexico City rankedthe highest congestion level on the road network, causing more than 90% extra travel time for citizens during busy hours. The traffic congestion impacts directly on the quality of life, however due to government policies that have encouraged the use of private transport,citizens prefer to use it instead of the public transport network. Nevertheless, public transport network offers a poor service. The aim of this study is to carry out a diagnosis about the public transport network in Mexico City by proposing a pertinent theoretical tool to optimize its operations on a daily basis. First, we present the official statistics about urbanization of Mexico City. Then, we present the official statistics about mobility. After that, we describe the components of the Mexico City public transport network. Finally, we propose a methodology to optimize operational aspects.

Keywords: urban mobility; optimization – simulation; synthetic microanalysis; Mexico City.

1. INTRODUCTION

"Adding highway lanes to deal with traffic congestion is like loosening your belt to cure obesity. – Lewis Mumford, The Roaring Traffic's Boom.

The activities of managing and planning of services in a context of cities entails a lot of work and participation of experts in different areas. Such is the case of transport that currently represents a challenge for researchers from different areas. There are three measures used for transportation analysis: traffic, mobility and accessibility (Litman 2011). As is observed in Figure 1, the aspects taken into account to compare the three measures are: definition of transportation, unit of measure, modes considered, assumptions concerning what benefits consumers, consideration of land use and favored transport improvement strategies.

On the other hand, politically Mexico City is divided by sectors (see Fig. 2), each sector has its own local responsibilities of management. We consider that a research about certain aspects of Mexico City should be conducted at different levels. For example, the first one can be done considering the complete city, at macro level.

	Traffic	Mobility	Access
Definition of Transportation	Vehicle travel.	Person and goods movement.	Ability to obtain goods, services and activities.
Unit of measure	Vehicle-miles and vehicle-trips	Person-miles, person-trips and ton-miles.	Trips.
Modes considered	Automobile and truck.	Automobile, truck and public transit.	All modes, including mobility substitutes such as telecommuting.
Common performance indicators	Vehicle traffic volumes and speeds, roadway Level of Service, costs per vehicle-mile, parking convenience.	Person-trip volumes and speeds, road and transit Level of Service, cost per person-trip, travel convenience.	Multi-modal Level of Service, land use accessibility, generalized cost to reach activities.
Assumptions concerning what benefits consumers.	Maximum vehicle mileage and speed, convenient parking, low vehicle costs.	Maximum personal travel and goods movement.	Maximum transport options, convenience, land use accessibility, cost efficiency.
Consideration of land use.	Favors low-density, urban fringe development patterns.	Favors some land use clustering, to accommodate transit.	Favors land use clustering, mix and connectivity.
Favored transport improvement strategies	Increased road and parking capacity, speed and safety.	Increased transport system capacity, speeds and safety.	Improved mobility, mobility substitutes and land use accessibility.

Figure 1: Comparing transportation measurements, reproduced from Litman(2011)

Figure 2: Mexico City sectors, reproduced from http://mapamexicodf360.com.mx/carte/image/es/mapa-delegaciones-mexico.jpg

While the second one should take into account the relationship between the different political sectors. Additionally, one should analyze each sector individually, at micro level. Last year Mexico City ranked the highest congestion level on the road network, causing more than 90% extra travel time for citizens during busy hours. The traffic congestion impacts directly on the quality of life, however due to government policies that have encouraged the use of private transport, citizens prefer to use it instead of the public transport network.

The aim of this study is to carry out a diagnosis about the public transport network in Mexico City for proposing a pertinent theoretical tool to optimize its operations on a daily basis.
This paper is prepared as follows: the official statistics about urbanization of Mexico City are presented in Section 2. The official statistics about mobility in Mexico City are shown in Section 3. The public transport network is described and a methodology to optimize its operational aspects is proposed in Section 4. Conclusions are drawn in Section 5.

2. URBANIZATION OF MEXICO CITY

As in the United States and Brazil, the majority of the Mexican population is urban (78% of population lives in cities), though this population grows at a slower rate (1.2% annually) compared to cities in China and India. Like in many countries around the globe, urban population in Mexico is growing at higher rates compared to the total population, making Mexican cities local engines for national growth, Varela (2015).

Table 1: Urbanization and economic growth, adapted from Tsay and Herrmann (2013)

	Countries				
	Br	C	I	Mx	USA
Population (billions)	0.5	1.3	1.2	0.1	0.3
Annual growth rate of population	0.83 %	0.46 %	1.28 %	1.07 %	0.9%
Urban population	87 %	47 %	30 %	78 %	82%
Change on annual level of urbanization (2010 – 2015)	1.10 %	2.30 %	2.40 %	1.20 %	1.20 %
GDP per capita (in U.S Dollars)	12,000	9,100	3,900	15,300	49,800
GDP growth rate per capita (annual percent in 2011)	1.80 %	8.00 %	4.90 %	2.70 %	1.00 %

Br-Brasil, C-China, I-India, Mx-Mexico, USA- United States of America

Moreover Varela (2015) points that "As competitiveness and growth in Mexican cities are increasingly compromised by congestion, air quality problems, and increased travel times; city officials not only face the challenge of accommodating a growing urban population but also sustaining a constant provision of basic urban services (e.g. clean water, health, job opportunities, transportation, and education). Unfortunately, periods of high growth without effective planning and increasing motorization, have pushed Mexican cities towards a "3D" urban growth model: distant, disperse, and disconnected. The 3D model is a direct result of national policies subsidizing housing projects in the outskirts of urban agglomerations, managing urban and rural land poorly, and prioritizing car-oriented solutions for transportation. As a result of this policies and trends, over the past 30 years Mexico City's population has doubled and its size has increased seven-fold." Now the alternative is a 3C urban growth model: Compact, connected and coordinated as is suggested by Floater et al. (2014).According to Varela (2015) Mexico City is the most populated metropolitan area in the western hemisphere. It concentrates 17% of the national population and account for 17% of the national GPD.

Table 2: Socio-economics KPI´s of Mexico City, adapted from CAF (2011a)

Administrative organization	The metropolitan area of Mexico is composed of 16 Delegations in the Federal District, 58 municipalities in State of Mexico, and 1 Municipality in State of Hidalgo.
Population (2008)	Federal District: 8.8 million Metropolitan area (Federal District and State of Mexico): 19.2 million
Area (2010)	Federal District: 1,487 km2 Metropolitan area: 7,180 km2 (40.1% of which is urbanized)
Population density (2010)	Federal District: 5,958 people/km2 Metropolitan area: 6,671 people/km2
Annual population growth rate (2005 - 2010)	Federal District: 1.49% Metropolitan area: 3.96%
GDP and growth (2011)	163.6 billion USD (17% of the national GDP, Federal District only) Annual GDP growth (2008-2011): 4%
Unemployment rate (2011)	6.5%

3. MOBILITY IN MEXICO CITY

Mobility in Mexico City is a huge problem since its size makes it insoluble. For instance, Table 3shows the trips in order the reader has a better picture.This table is very important for the analysis since it can be used at the different levels, micro, mezzo and macro. Just as it was established in Table 1, the emphasis has variations in accessibility, mobility and traffic.From the macro level perspective it is necessary to consider the whole city as a complex network system, in such a case the connectivity has a major role, in order to show this in next section public transportation networks maps are presented and analyzed.

4. THE PUBLIC TRANSPORT NETWORK IN MEXICO CITY CONTEXT

As can be observed from Fig. 3 to Fig. 4, the public transportation networks are constituted by other networks.

Figure 3: Metro and Metrobus networks, reproduced from http://www.juliotoledo.com

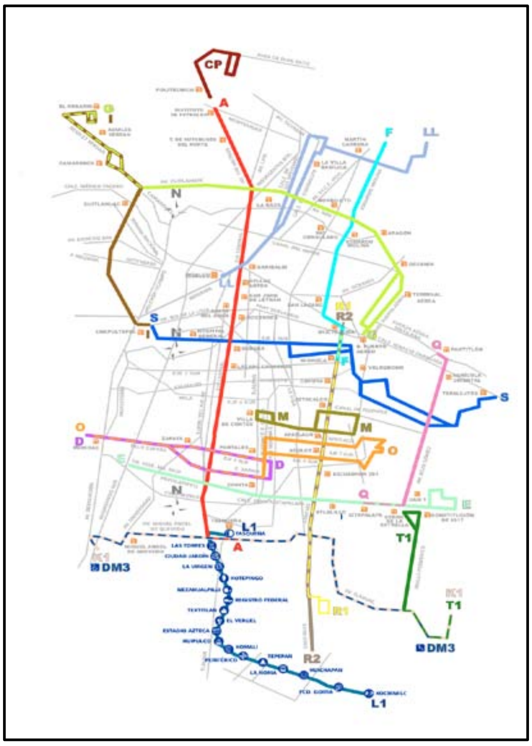

Figure 4: Electric bus network, reproduced from http://www.juliotoledo.com

According to Varela (2015), the management of the public transport in Mexico City is fragmented and this makes it difficult to establish some planning policies for its improvement (see Fig. 5).

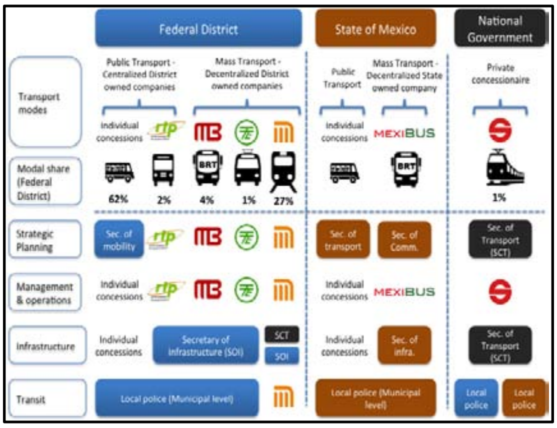

Figure 5: System of governance for public transport in Mexico City, adapted fromVarela (2015)

"Such institutional and operational fragmentation has significant implications especially for users. In Buenavista - an area of Mexico City where three modes of transport converge – travellers must walk up to 1.5 km to transfer from one mode to another. Close to 150,000 users everyday use this disconnected transport hub with significant costs for users as well as for operators" Varela (2015).

Figure 6: Modal connection in Buenavista, adapted from Varela (2015)

The public transport networks in Mexico City are considered complex and both vulnerability andresilience are important factors for taking into account. As Reggiani (2015) states, the following questions that need to be answered:

1. Is a complex network a necessary condition for the emergence or presence of transport resilience and vulnerability?
2. Several indicators of resilience and vulnerability co-exist; are these differences related to specific fields of transporta tion research?
3. (c) Can connectivity or accessibility be considered as a unifying framework for understanding and interpreting – in the transport literature – the concepts of resilience and vulnerability?

In relation to the first question, we should bear in mind that ‘‘the term ‘complexity’ embeds both the assemblage of different units in a system and their intertwined dynamics. In other words, the term ‘complexity’ is strictly related to the concept of networks’’ (Reggiani, 2014, p. 814). Furthermore, connectivity, i.e. the ability to create and maintain a connection between two or more points in a spatial system, is one of the essential elements that characterize complex networks. Given the relevance of the connectivity pattern in complex networks, it may seem plausible that complex networks – and connectivity – are a sine qua non for the development of resilience and vulnerability in transport systems. Recent studies show how the topological properties of a network can offer useful insights into the way a transport network is structured and into the question of which are themost critical nodes (hubs). Resilience and vulnerability conditions associated with such hubs can then impact on the resilience/ vulnerability of the whole network. For optimizing urban mobility in Mexico City, we propose to carry out a network analysis based on traffic, mobility and accessibility aspects to develop a simulation model. Additionally, we consider that the lack of connections in the multimodal network could be tested based on some algorithms. According to Sochi (2011), three main methods can be used for this purpose: Direct inspection, Node Mapping and Segment Mapping. The segment mapping method is highly efficient method, the search for connectivity starts from seeding a list of connected nodes by the two nodes of a randomly selected segment. By going through the remaining segments and adding the node of any segment whose other node is found on the connected nodes list, a connected partition, which possibly comprises the whole network, will gradually build up. All segments whose nodes are added to the list are removed from the segments list either directly or by the use of a labeling mechanism such as a Boolean array to mark the status of thesegments as being removed or not.

The inspection of the segments list are repeated until happens one of the two conditions:

1. The segments list is empty (in which case the network is totally connected).
2. The inspection of all the remaining segments in the list in one of the iteration cycles returns no new nodes to be added to the connected nodes list (in which case the network is dismembered and partially connected).

In the latter case, this inspection process is repeated iteratively to identify all the partitions of the network until the exhaustion of the entire segments list. The input data required for this method is a list of the network segments where each segment is identified by the indices of its two end nodes. Sochi (2011).

5. CONCLUSIONS

Recent studies have been made on mobility in Mexico City have a transportation management approach and proposals for improvements in mobility, mobility indicators and policies to follow. While they are important, they have not used a systemic approach and made use of quantitative tools such as simulation and optimization.

As we can see the analysis proposed is innovative because it considers the transport network as a complex network that has as an important issue the disconnection.

At a macro level connectivity analysis is verified through an optimization algorithm, then the simulation is used to design simulation scenarios and search for feasible solutions with respect to environmental, land use, travels data and budget constraints.

For future research some results in the macro level will be available, a mezzo and micro level analysis will be developed, always considering aspects of traffic, mobility, and accessibility.This study will be done for a sector of the city of Mexico with data provided by the respective authorities.

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Table 3: Mobility in Mexico City, adapted from CAF (2011b)

<table>
<tr><td colspan="8">Mobility KPI´s for Mexico City during 2001, 2007 and 2010</td></tr>
<tr><td colspan="2">Total trips per day (2007)</td><td colspan="6">48.8 million (Metropolitan area) and 32.0 million (Federal District)</td></tr>
<tr><td colspan="2">Daily trips per person (2007)</td><td colspan="6">2.5 (Metropolitan area) and 3.6 (Federal District)</td></tr>
<tr><td colspan="2" rowspan="12">Trips and modal share in the Federal District (2007)</td><td colspan="2">Mode</td><td>Trips</td><td colspan="2">% Total</td><td>%Public transport</td></tr>
<tr><td colspan="2">Non motorized</td><td>8,600,000</td><td colspan="2">26.9%</td><td></td></tr>
<tr><td colspan="2">Prívate vehicles</td><td>4,800,000</td><td colspan="2">15.0%</td><td></td></tr>
<tr><td colspan="2">Microbuses</td><td>9,448,800</td><td colspan="2">29.5%</td><td>50.8%</td></tr>
<tr><td colspan="2">Metro</td><td>4,984,800</td><td colspan="2">15.6%</td><td>26.8%</td></tr>
<tr><td colspan="2">Autobuses</td><td>1,878,600</td><td colspan="2">5.9%</td><td>10.1%</td></tr>
<tr><td colspan="2">Taxis</td><td>1,041,600</td><td colspan="2">3.3%</td><td>5.6%</td></tr>
<tr><td colspan="2">Metrobus</td><td>762,600</td><td colspan="2">2.4%</td><td>4.1%</td></tr>
<tr><td colspan="2">Trolley (RTP)</td><td>204,600</td><td colspan="2">0.6%</td><td>1.1%</td></tr>
<tr><td colspan="2">Suburban train</td><td>167,400</td><td colspan="2">0.5%</td><td>0.9%</td></tr>
<tr><td colspan="2">Light train</td><td>111,600</td><td colspan="2">0.3%</td><td>0.6%</td></tr>
<tr><td colspan="2">Total</td><td>32,000,000</td><td colspan="2">100.0%</td><td>58.1%</td></tr>
<tr><td colspan="2">Road network (2007)</td><td colspan="6">10,200 km (91% local roads)</td></tr>
<tr><td colspan="2" rowspan="10">Total vehicles (Federal District, 2001)</td><td colspan="4">Cars</td><td colspan="2">4,460,386</td></tr>
<tr><td colspan="4">Taxis</td><td colspan="2">225,302</td></tr>
<tr><td colspan="4">Motorcycle</td><td colspan="2">11,920</td></tr>
<tr><td colspan="4">Microbuses</td><td colspan="2">20,459</td></tr>
<tr><td colspan="4">Buses</td><td colspan="2">8,240</td></tr>
<tr><td colspan="4">Combis</td><td colspan="2">3,519</td></tr>
<tr><td colspan="4">Metrobus – articulated buses</td><td colspan="2">322</td></tr>
<tr><td colspan="4">Metrobus – regular buses</td><td colspan="2">54</td></tr>
<tr><td colspan="4">Metrobus – biarticulated buses</td><td colspan="2">27</td></tr>
<tr><td colspan="4">Totals</td><td colspan="2">4,730,228</td></tr>
<tr><td colspan="2" rowspan="4">Road safety (2010)</td><td colspan="4">Total number of accidents</td><td colspan="2">14,729</td></tr>
<tr><td colspan="4">Number of deaths</td><td colspan="2">1,026</td></tr>
<tr><td colspan="4">Involved vehicle in deaths</td><td colspan="2">3.5% Microbus
81.0% Car
5.6% Truck</td></tr>
<tr><td colspan="4">Involved victim in deaths</td><td colspan="2">14.0% Motorcycle driver
52.0% Pedestrian
20.0% Car driver</td></tr>
<tr><td rowspan="4">Emissions (contribution by vehicle type) (2006)</td><td>Pollutant</td><td>Cars</td><td>Taxis</td><td>Microbuses</td><td>Buses</td><td>Motorcycles</td><td>Trucks</td></tr>
<tr><td>CO2</td><td>58.0%</td><td>6.2%</td><td>13.2%</td><td>1.9%</td><td>6.0%</td><td>14.7%</td></tr>
<tr><td>NOx</td><td>46.2%</td><td>6.9%</td><td>11.4%</td><td>10.2%</td><td>1.0%</td><td>24.3%</td></tr>
<tr><td>PM2.5</td><td>14.2%</td><td>2.4%</td><td>1.6%</td><td>25.2%</td><td>1.5%</td><td>55.1%</td></tr>
</table>