TRAFFIC EVALUATION IN A MID-SIZE CITY UNDER POOR KNOWLEDGE CONDITIONS

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ABSTRACT

The increased mobility of people and goods in mid-size cities in Mexico has lead to a growth in traffic congestion. To analyze this and other transportation problems it is necessary to obtain data about the daytime and night-time population distribution in a mid-size city, the traffic intensity in the different city zones and the main obstacles in achieving regular traffic flow in urban areas. Simple models and tool-kits have been used and/or adapted to obtain the necessary data in order to determine the following: the discrepancies between the centres of daytime and night-time population distribution, the intensity of transport flows in different parts of the city and to establish nodes and causes of congestion due to people movement. This information will be useful in developing a series of recommendations to improve the urban traffic system in the sample city.

Keywords: Model of urban traffic, Population distribution, urban traffic network.

INTRODUCTION

Mexican cities with a population greater than 40,000 have been experiencing increased traffic problems caused by a rise in the number of cars on the road over a short period of time. This particular problem has been made worse by the failure to carry out essential improvements to the roads, little or no regulation of the urban transport system and a general lack of urban planning. This has lead to a shortage of parking facilities, resulting in cars being parked erratically and obstructing traffic flow. Small-size cities, approximately two kilometres in diameter, have no significant traffic or transportation problems, as average journey distances are shorter than those in medium or large-size cities. Mid-size cities in Mexico with more than 130 vehicles per 1000 persons suffer from various problems such as traffic congestion, a lack of parking spaces, restricted access for emergency services and to institutions, to name but a few.

For large cities, the macroscopic traffic simulation is usually applied as a changeable element in urban planning: main and peripheral roads, leisure facilities (cinemas, shopping complexes, tourist attractions, etc.) and urban infrastructure (bus stations, etc). This simulation requires specific information about the key nodes in different parts of the city at different times of day under different traffic situations, such as weekdays, leisure, holidays or one-off special events. When creating a road network model one also needs to know the distribution of routes taken by public and private transport throughout the city, as well as the departure and arrival points throughout the day. This requires putting expensive monitoring systems in place which is not a viable option for small and medium-size cities.

Substantial research has been carried out on transportation problems in large cities, where transport is an important element of a complex urban system, (Forrester, 1969 and Warne, 1992). We are also familiar with decision models of transportation problems, such as linear programming of transportation problems and the shortest route problem (Taha, 2007). We try to avoid referring to articles about traffic in towns which are covered by the references and sub categories relating to transportation planning (Florian, 2008). We did, however, use one article which proved very useful when analyzing our particular case.

Expensive commercial software is available for dealing with transportation problems in large cities. These software packages need a lot of raw data to be collected. It is necessary to put a monitoring system in place to obtain the information required in order to create a database of urban and transportation systems of a town or city. The cost for this type monitoring is so high that it cannot be met by the municipal government of a medium or small-size city, even less so when officials don't consider transport planning a priority. Municipal governments store a lot of valuable data which could be useful for analyzing transportation problems, but it is usually very difficult to access this information.

To solve the problems caused by urban traffic in a mid-size city, we are required to use traditional mathematical model of the traffic system (Ortúzar and Willumsen's, 2008). It is also worth mentioning the model put forward by Hensher and Button (2008) which states that most journeys originate from the home or workplace, a model based on peak hour traffic.

The sample city for this investigation, Huajuapan de Leon, has a public transport system consisting of shared taxis, and so it is therefore considered as a public transport/private vehicle split model. In this case, the model has to contain:

- Night-time and daytime population distribution;
- Traffic network structure and capacity;
- Distribution of flows of trips within the traffic network (route choice).

Once this investigation has been carried out, it will be possible to identify the problem areas, create a database which contains information on traffic behaviour and then propose solutions to deal with traffic congestion and other related issues. In order to try out and develop these models, the city of Huajuapan de Leon, Oaxaca, located in the south of the Mexico, was chosen as the main sample for modelling. The city is home to more than 50,000 people and

there are more than 135 cars per 1000 people. Huajuapan's geography is typical of many mid-size cities in mountainous regions: there are a lot of obstacles (gullies, ravines and gorges) hampering the development of a weather-proof road network on the outskirts of the city. The road network and main problem areas in Huajuapan are presented schematically in figure 1. The rectangular shape represents the "old central area" while the outer lying parts of the city form a star shape. One can already see the potential for traffic congestion problems.
Simpler or scaled down versions of tools and methods used for obtaining information will be sufficient for this particular investigation. These techniques are based on general information about the city and hypothesis on the behaviour of people with different lifestyles. Additionally, these methods are cost effective and could be used to carry out a quick preliminary analysis of different scenarios by specialists.

The problem can be divided into two stages: obtaining the information about night-time and daytime population distribution, and then using this information with tried and tested standard mathematical approaches to solve the transportation problems.

A SIMPLE TOOL FOR THE STATICAL EVALUATION OF POPULATION DISTRIBUTION.

A distribution of the night-time population was obtained digitally with a tool called "Picture", (Makagonov, Sboychakov and Sánchez, 2007). This program can determine the boundaries of neighborhoods, or "colonias" as they are known; small self-governing zones in most Mexican cities. Typically, these areas have a large number of dwellings and are densely populated. The results generated by this program are three spatial characteristics of every residential zone: the total area of the zone, coordinates X, Y and the centroid of the area, which is the centre of a geometric mass of uniform density. Figure 1 shows the results of an analysis performed by the "Picture" program for the small town of Skalica in Slovakia.

The symbols ◊ - 1 show all the centroids of the residential zones (represented by dark grey) and the centroids of zones of daytime activity (light grey). From the resulting data, one can see that with the addition of area centroids, it is possible to substitute continuous spatial distribution by an efficient points system with a weighting coefficient equal to the area of the corresponding zone. In this case, the letters D and N indicate centers of daytime and night-time territories. The coordinates (X, Y) are calculated by formulas for centers of gravity and mass. In small zones, the points (D and N) provide a fairly accurate picture of areas which are places of daytime activity and night-time activity. If the population density in residential zones is uniform then the N-point is also the center of night-time population. But it is difficult to imagine that the active population density in the zones of daytime activity is also uniform. So for the model of night-time distribution we accept the hypothesis of uniformity but not for the daytime distribution.

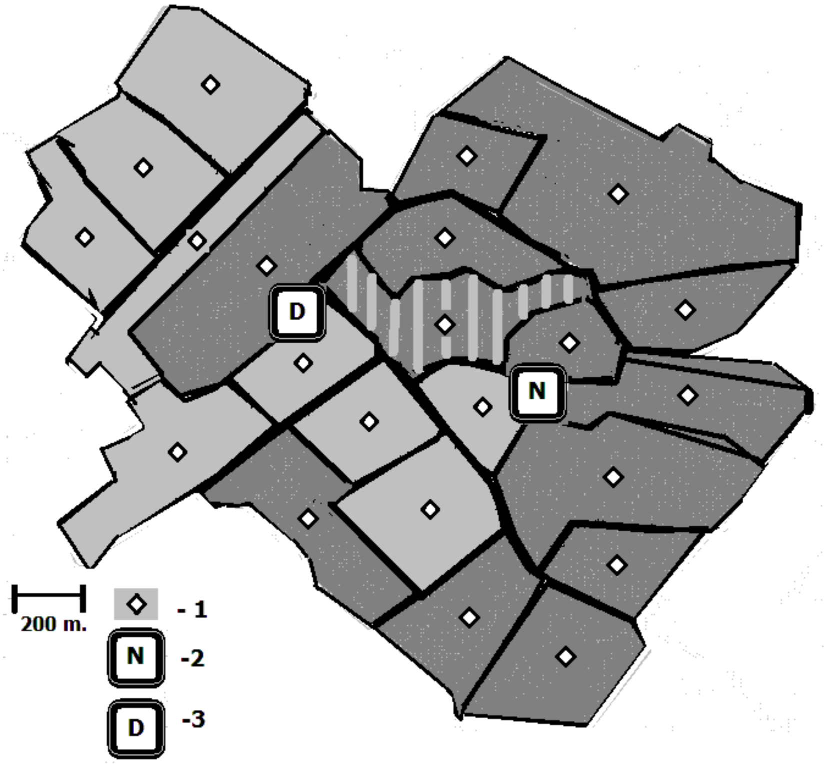

Figure 1. Distribution of centroids (◊ - 1) of dwelling zones (dark grey areas), centroids of daytime occupation zones (light grey colour), the city-centres of gravity of daytime activity (D-3) and resident territories (N-3).

An analysis of all the residential zones was carried out using the “Picture” program to obtain a set of points. The residential zones, such as neighborhoods and housing developments are represented as focal points with the coordinates representing the center of a designated area. The characteristics of these zones, such as the population of every zone, or quantity of children of school age have been calculated as a proportion of the total number. From different sources we can conclude that Huajuapan has a population about 45, 300 citizens (INEGI, 2010). Children represent 37% of the total population, or 16, 761 citizens.

A small proportion of the children attend kindergarten, while nearly all other children attend school from the age of 6 years, accounting for 12/17 or 70.6% of all children. We then evaluated the total number of pupils in all educational institutions (not all the private schools were ready collaborate with us so we made estimates) and the figure came to 11, 600 pupils, (70.6 % of 16, 761 is 11, 831), a discrepancy of less than 2%. Although collecting this data was time consuming and laborious, it was necessary for our models. It must also be pointed out, however, that some experts argue that this kind of data is immaterial and that Ortuazar’s “home interview travel survey data” (2008) can be used in its place.

As regards to occupational patterns (retail trade, taxi services and social services are the main activities), places of employment and education are better represented from the very beginning as a set of points based on traffic flow features such as streets and avenues with good accessibility. We had to analyze the total number and types of workplaces in the city by undertaking field observations and expert evaluations. We included locations which started activities between 8 and 9 o'clock in the morning, the time of day when most of the population start their daily activities.

Most people make at least two trips from their permanent residence to their main activity and back every working day or at least a few times a week. This kind of movement is known as "pendulum migration". So, the model of population distribution and active population is represented by a system of points located in the center of different zones. Examples include a housing complex, neighborhoods or a workplace which could be the points of departure and arrival that correspond to the migration pendulum present in every working day.

The simplest way to evaluate the size of a pendulum migration problem is to calculate, by existing formulas for centers of gravity and mass, the places of daytime and night-time activity. In other words, when the coordinates of centroids are calculated, it is possible to use static moment (first moment) formulas for coordinates X and Y, which are then combined to observe the axis of daytime and night-time activity distribution points with different weightings.

Firstly, if there is a discrepancy in daytime (X_D, Y_D) and night-time (X_N, Y_N) values then the city has problems of daily pendulum migration. The results of these calculations are presented in the table 1.

Table 1. Statistical characteristics of population distribution in the city of Huajuapan.

Distributions	Characteristic	X average (meters)	Y average (meters)	Standard deviation X: σ_X (meters)	Standard deviation Y: σ_Y (meters)	Correlation moment: K_{XY}
Places of employment	Quantity of employees daytime (4789)	1488	1011	9.05	974	0.13
Places of education	Quantity of students and teachers (11681)	1115	702	1399	1202	0.14
Daytime population	Quantity of population (16470)	1223	790	1286	1149	0.15
night-time population	Area of residences	490	1180	1580	1248	7.31

From the table, it is possible to calculate the distance between the center of distribution of the night-time population (***N***) and the centers of daytime activity (***D***) and separately for centers of education (***E***) and work (***W***). Therefore, we can see that:

- The centers of daytime and night-time population have a distance of 850 meters. The active population moves this distance at least twice a day, and it is an additional daily trip compared with the cases of non-shifted centers of daytime and nighttime scattering. The work places are mainly concentrated in the "historical center of the city", but it is not the geometrical (geographical) center.

- The centers of student population have a difference of 484 meters from the centers of working population. Therefore, parents that take their children to school on the way to work need to travel an extra kilometer each day.

- The most important figure is the standard deviation between the centers of daytime and night-time population. For the daytime population there is a spread of population towards east west of ±1286 meters; towards north south it is ±1149 meters. The nighttime population shows a spread in the direction of east west of ±1580 meters and towards north-south it is ±1248 meters.

- The standard deviation shows the distribution of daytime and night-time population and the S zone ($S = \pi \sigma_X \sigma_Y$ [m^2]) with a concentration of 60% of the population.

- If the centers splice, but the instances of second order are the same, then the distribution of places to sleep and places of work will be basically the same, and this could help to reduce the problem of pendulum migration, thus reducing the chances of bottlenecks in road traffic and preventing wasted time for the active population.

- It can be noted that the daytime population is located in a more compact manner than the night-time population. This can be observed comparing the standard deviation of the work places with the nightly population that is more than 1.66 times of the X axis and 1.29 times more for the Y axis. If this distribution represents 60% of the population in the interior zone of the north-south and east-west axes, then this distribution changes its origin 850 meters every day and the axis of nightly distribution is 67% more in the east-west direction and 23% more in the north-south direction.

A SIMPLE SEMIMANUAL METHOD TO EVALUATE THE ROADS AND TRANSPORT VARIABLES

Following the statistical evaluation we now have data about:

1. An active population in zones of (night-time) residences which could potentially inform us on the number of trips departing from place of origin to a certain destination (places of work, study, service, etc.);

2. The potential for evaluating the number of trips arriving at destinations of employment and educational zones.

To evaluate traffic intensity we have to become familiar with the flow of journeys, and for this we need to create an origin-destination demand matrix which provides further data about demand for travel. With an origin-destination demand matrix it is possible to solve the problem of minimizing transportation costs from all departure points to the final destination with the requirement that the sum of all departures is equal to the sum of all arrivals. The matrix was constructed for morning trips only, so the matrix (n×n) was used, where n is the total number of zones, so there are two matrixes. For the first matrix the points of origin are 106 points of departure from residential zones, while the points of destination are 17 educational institutions (clusters). For the second matrix we have 106+17 points of departure, which are residential zones and points of education, while there are 36 points of destination, which are places of work (clusters). With this matrix dimension it is not difficult to resolve urban transport problems with simple tools. Traditionally, Wilson's entropy maximization model is used in such cases, employing the non-linear optimization method. However, with our preliminary analysis using restricted information, we preferred traditional approaches to resolving transportation problems in linear programming, where the objective function is linear and we can use the standard tool-kit Tora (Taha, 2007), which is sufficient for our transport problem matrix dimensions.

To apply the above method, we have to put forward a hypothesis on "the reasonable behavior of the population", which in our case is that each employee selects his/her place of work and each pupil his/her school, all the while applying the criteria of minimization of travel time. This hypothesis is only applied if all the work places and all schools are of the same quality and the individuals don't have any preferences for one site over another. Unfortunately, this is not always true. For example, schools in Huajuapan have different academic levels and different costs, but these variables aren't taken into account in the optimization criteria. A solution to these types of issues in mid-size cities is a clustering of the educational institutions in the same vicinity (a group of institutions with different characteristics). This cluster forms a concentration of educational institutions with different qualities. Thus the need for parents to make difficult decisions about which school to choose is reduced or eliminated by means of substituting some educational zones for clusters. As such, the choice of arrival place (schools), doesn't depend on social criteria, it depends on the need to minimize the travel time by the population. The same effect is present when clustering the places of work. For the clustering, the procedure of grouping the nearest neighbors into one cluster is used (Makagonov and Sboychakov, 1998).

As one of our main objectives is lowering transport costs, we need some method of calculating the cost of every trip between all points of departure and arrival. Instead of distance, it is more beneficial to consider the average duration of the trip. For example, it is possible to calculate the time of a trip in a car from one's house to one's place of work or study. This kind of trip in a mid-size Mexican city has three stages: using minor roads to access the main road, using the main roads to save time and then leaving the main road using minor roads. Sometimes it is better not to measure the distance lineally, but metrically, where it is measured by space and time. For example, in the city of Huajuapan, statistics indicate that 5 minutes is necessary to complete most journeys using the main road, including the time it takes to heat the car engine, to get the kids in the car, for the kids to get out and go to school or for the driver to reach their place of work. In addition, there are also speed limits of 40 Km/h by traffic lights, so it is possible to conclude that 1 minute is needed for every 667 meters (40000 km/h X 1 (h/60min)) =667 meters/minute). The Euclidean distance between the opposite vertices of square (with unit area) is 1.41. The shape of the route, however, is often less than a diagonal square, and then a factor of 1.2 is used for each distance $\boldsymbol{D_{i,j}}$ between points of departure and arrival by air. Hence the formula for the $T_{i,j}$ - time of arrival from point ***"i"*** to point ***"j"*** in minutes is

$$T_{i,j}=5+D_{i,j}*1.2/667 = 5+D_{i,j}*1.8/1000$$

A timeframe of 5 minutes is needed to complete most journeys using the road network, from the starting point to the final destination. The citizens of Huajuapan have a habit of using automobiles (private vehicles or shared taxis) for journeys of 1 kilometer or more. On the other hand, a vehicle is not used for journeys that take 8 minutes or less. We can therefore omit all trips shorter than 8 minutes from the results of the transport problem solution. We then need to correct the point of departure for some parents: they don't start from the school zone but from their houses. The quantity of cars in Huajuapan (including shared and private taxis) is greater than the number of work places due to high levels of emigration.

As mentioned before there is the second stage to the transport problem solution; dealing with the group of parents or guardians that take their children to school and then travel to their jobs on their everyday journeys. This is why it is necessary to resolve the transport problem with linear programming in two stages: the first step is to resolve the problem of the point of departure (housing) and the point of arrival (schools or workplaces for people without children). The second stage deals with the point of departure (schools) and the final destination (workplaces or housing for people that don't work). At first glance, the formula for this problem is the same as Wilson's model but the objective function is linear and that leads to a scaled down or less complex version of the model and consequently the problem.
For the next step we a need a simple solution to the traffic problems as the layout of the current road network leaves us with very few alternatives. Every route is represented by a chain of arcs with nodes at the crossroads. The majority of the arcs on the road network are one-way streets. Another drawback is that Huajuapan has a specific road structure: a star shape on the periphery and a rectangle in the downtown area, located on a flat terrain.

The new residential zones, however, are separated from one another by ravines and streams and the lack of roads makes it more challenging to reach downtown. Although there is a smaller population in the outer lying areas, traffic bottlenecks do occur en route to some downtown areas. The road graph can be simplified by eliminating peripheral branches and looking for an optimal route. The peripheral parts have formed a tree-like graph and alternative weather-proof routes do not exist for these zones. So, most attention should be paid to the central nodes when looking for optimal routes to alleviate congestion. There aren't many options as there is a one-way traffic system in most parts of the center. That is why we only have 67 nodes all over the network with 10 points of entry indicated in figure 2 by grey circles with a black outline.

Figure 2. Generalized scheme of transport network of Huajuapan City. 1- Points of entry to developed part of network from access-roads. 2 - (N) - center of domiciles (night population) distribution); 3 – (D) – centre of workplaces (day-time) distribution.

The lack of options raises the possibility of looking for a solution manually, so we calculated the distribution of traffic flow in the following way:

- For every of 10 points of entry (and exit) we calculated the total number of input and output flows for all the points of departure and arrival out of a nuclear (central) zone. After this, the optimization process was restricted to the nodes and arcs of the digraph (oriented graph). Every flow of traffic was divided into six parts (each being 10 minutes between 7:30 and 8:30 in the morning of the working day)
- For every source (node) of departure and arrival we built the "quasi-optimal route" manually and put the flow intensity into the chain of arcs between them with a correction of the time elapsed in accordance with the remoteness of source. The only alternative to this approach were routes located in the downtown area.
- The accumulated sum of flows (two sums in the case of the bidirectional arc) for every 10 minutes became the focus of analysis in order to establish the maximum number of flows. We concluded that a car did not have difficulty moving if the length of the arc divided by quantity of cars was more than 25 meters. When speed is 40km/h or 11.11 m/sec then a car completes 25 meters in 2.25 seconds. So, for time (T seconds) the quantity of cars in the length arc L can't be more than L/25+T/2.25 units. The large number is a warning sign of potential traffic congestion in the future.

The transport flow measurement field work was carried out at the four busiest crossroads near education and work zones at 8 o'clock in the morning. After two days research, we established that the discrepancy in our results was about 10%. The local road and urban transport authority confirmed the accuracy of the results and the need for this type of information in developing urban management projects.

To reduce the effects of this problem, it is useful to establish the desirability of some areas over others. In order to do this, we used a different set of models. We chose a desirability model $F_{i,j}$, for zones of daytime activity (index ***j***)) and for places with a high concentration of night-time activity (index ***i***).

$$F_{i,j} = \frac{M_j \cdot M_i}{d^2_{i,j}}$$

Where:
$d_{i,j}$ is the distance (for example, the mean duration of the trip from point a to point i), M_j is the characteristic of desirability of point i for citizens (good schools and employment prospects, for example),
M_i is the capacity of the point ***i*** (for example, the size of the residential zone or the number of inhabitants).

This preliminary analysis has revealed that there are serious issues regarding traffic management in Huajuapan. Another factor is that small values of desirability $F_{i,j}$ can be used to eliminate some columns and/or rows associated with the destination demand matrix which simplifies the problem somewhat. There are also some ideal locations for relocating large companies away from the city center as well as for establishing new residential zones. Better organization of the road network for increased and rapid traffic flow would allow easy transportation of the local population to and from their daily activities.

CONCLUSIONS.

Normally when designing an urban development proposal, the local government first produces a viable scheme taking into account all factors relating to transport in and around the city. It is only once such a scheme has been developed that a cohesive and integrated transport system and road network can be implemented. The city of Huajuapan has now reached a point where it has to take strategic decisions regarding public transport and private vehicles. Public transport, as has been demonstrated in many European cities, is the only solution for providing quick access to the central zone of a city

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Due to a lack of readily available data in Huajuapan it was necessary to carry out extensive research in order to obtain the information needed. Some of the processes and tools for data collection mentioned in this paper were able to compensate, at least temporally), for of lack of municipal government resources.

These models and results can be implemented in the future with other traditional graph theory methods to tackle the problems of urban transport.

The main objective of this investigation was to put forward some suggestions to the local transport authority of Huajuapan de Leon on how to deal with its traffic problems. We have shown the main problem areas and congested spots around town with simplified models and made a series of recommendations.

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