DIAGNOSTIC AND TREATMENT OF THE "SPLIT BRAIN" OF AN ISLAND: TRAFFIC ANALYSIS OF EL-CARMEN CITY

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INTRODUCTION

El-Carmen is a city into an island within an ecological reserve area (mangrove area) and near an important petroleum oil field in the Golf of Mexico. The city has over 166 thousand inhabitants. A particular characteristic of El-Carmen city is that, its international airport is in the middle of the island splitting the city into two parts, as shown in Figure 1. Eastern and western parts of El-Carmen City are just connected by one regional road and one local street. This situation is similar to the result of a split brain surgery, which partially or completely disconnects the corpus callosum of epileptic human patients.

Corpus callosum is a thick band of fibers connecting the left and right hemisphere and allowing them to communicate and coordinate thoughts, feelings, and actions (Robinson, 2009). The two hemispheres are highly specialized for certain tasks; then the lack of communication between them could produce abnormal behaviour in patients.

Analogously to a split brain, El-Carmen City has two specialized parts. The majority of the service-land-use is within the western part. The market, offices, schools and the Port are located there; also the offices and facilities of PEMEX (Mexican Petroleum Company) and the companies whose services are related to the petroleum extraction are located there. Almost there are not free plots in the western part. Instead, the eastern part has mainly residential land-use and available plots for a future urban development, and includes a portion of the ecological reserve area (see Figure 1).

The island is connected with the continent by means of two bridges, which are located in the western and eastern extreme points. The seaport and the airport are important for the national petroleum industry, hence they can not be relocated; the city exists because of them and the majority of the jobs are related to the petroleum industry and general services.

The motorization rate is high and it is growing very fast. Almost 33% of the trips (of people over 15 years old) use private car. Near 41% of the trips at the morning rush hour use private car (see Figure 2).

This paper presents a peculiar traffic analysis, which was made for El-Carmen City. The city and its behaviour are compared with some possible consequences of a split brain surgery, due to the limited communication between the two parts. First, the current characteristics of the road network and public transportation in El-Carmen City, as well as its future growth and road projects, are presented. Then, the "split brain" diagnostic is described. Later, the flow estimation for present and future scenarios is described. As a result, a treatment is suggested, which is then presented. Finally, some conclusions and references are presented.

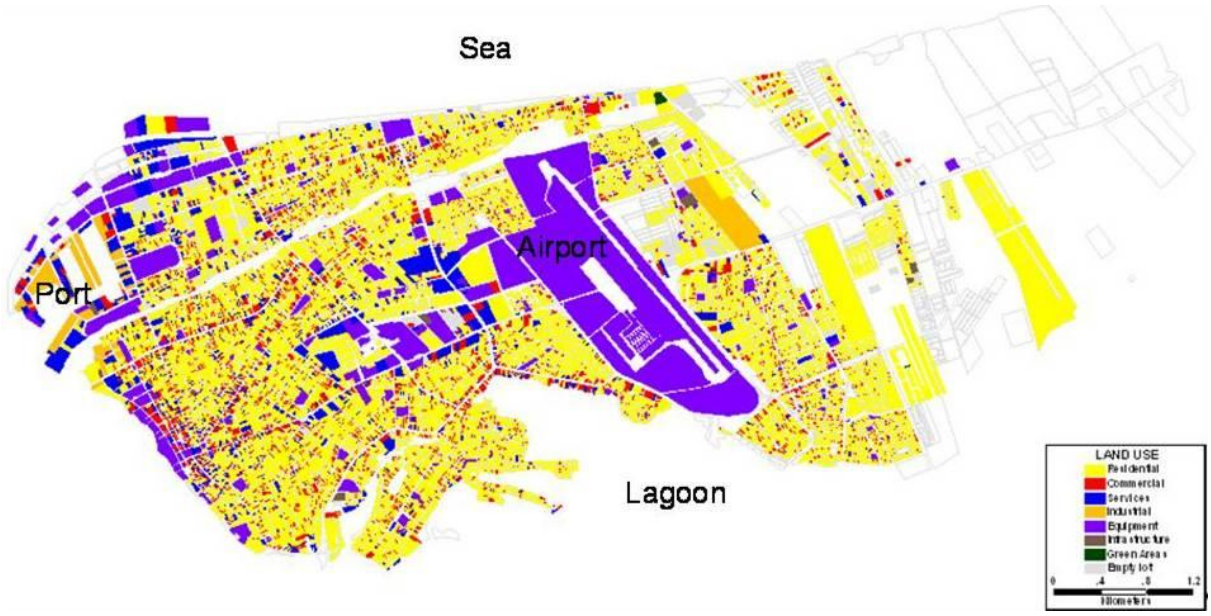

Figure 1. Land-use in El-Carmen City

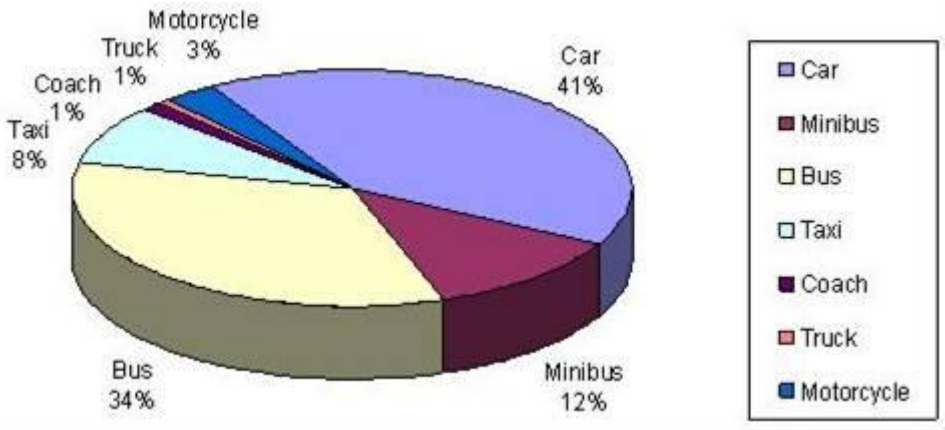

Figure 2. Transportation mode of trips at the morning rush hour (8-9am)

TRANSPORTATION IN EL-CARMEN CITY

On one hand, the particular urban structure of El-Carmen City produces a large quantity of trips between the two parts of the city. Usually, trips go from east to west during the morning and from west to the east during the afternoon-night (home based work HBW and home based other HBO trips). The majority of the jobs and services are located in the western part. Additionally there is a large amount of in-transit trips which cross the city in both directions.

On the other hand, only two pathways connect the eastern and western parts of the city, the current road network is limited and the public transportation routes are deficiently designed. Hence, El-Carmen City suffers multiple traffic congestion problems especially at rush hours.

This situation is a consequence of the lack of urban management for many years, which is normal in cities of developing countries.

Fortunately, El-Carmen City government is starting planning. They created a plan which considers future urban spot growth and land-uses, and some ideas for new road infrastructure.

Current Road Network and Public Transportation Routes

In El-Carmen City, the unique two pathways between the eastern and western parts are a regional road with a large amount of in-transit vehicles, with two lanes per direction, classified as an urban highway, and a street with just one lane per direction, classified as collector. The former one cross the island (red arcs in Figure 3), generating a bottleneck in a regional road system. The latter one is used by PEMEX's trucks for going to the seaport; hence, materials for maritime petroleum platforms use it. This street is also the front beach street (which disappears during the hurricanes period), where a combination of large trucks and tourist vehicles exist.

Additionally, the city has limited urban network and public transportation system, which make even more difficult the trips between the eastern and western parts of the city.

Figure 3 shows the streets, which are classified into urban highway, arterial, collector and local. In the western part, there are few arteries and many of them are narrow, with two lanes in one direction (black arcs in Figure 3). Very narrow local and collector streets are located in El-Carmen City downtown, which is on the extreme western part. The network is even more limited in the eastern part.

The public transportation system is deficient; routes are mainly concentrated on the same arcs (see Figure 4). Some of these arcs belong to the main artery in the western part and others belong to the urban highway; traffic lights are in both kinds of arcs.

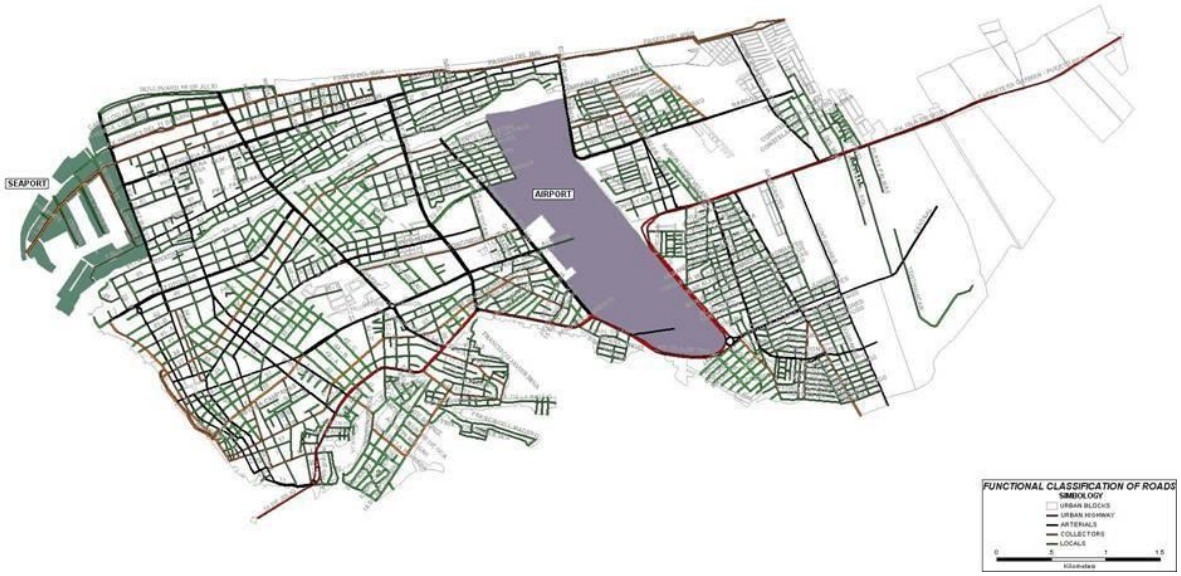

Figure 3. El-Carmen network, 2008

Figure 4. Public transportation routes

Therefore, traffic problems and congestion are a common situation in El-Carmen City, especially in downtown and on the urban highway.

Future growth

The traffic problems can be worse in the future, considering that population is growing and urban spot is extending on the eastern parts of the island.

The Urban Management Plan for El-Carmen City 2009-2015 ("Programa Director Urbano 2009-2015, Ciudad del Carmen") (IMPLAN, 2009) establishes the areas where future urban growth is proposed, assigning recommended land-use to each area (see Figure 5). We assumed that such plan will be respected in the future.

The areas to be developed are basically in the eastern part of the city. They mainly include residential and mixed-residential land-use (yellow colour), urban sub-centre (red colour), equipment or urban infrastructure (blue colour) and shops, warehouses and low impact industry (purple colour).

Based on the current population, land-use and road network, 100 Traffic Attraction Zones (TAZ) were determined. Later, based on the future urban growth, 12 new TAZ were defined, as shown in Figure 6. A TAZ is considered as a homogeneous area where trips are generated or attracted.

El-Carmen City population was 154,197 inhabitants in year 2005 (INEGI, 2005). The Demographical Study for El-Carmen City ("Estudio Demográfico, Ciudad del Carmen, Campeche" (IMPLAN, 2007) contains projections of population and housing for 2005-2035 period, where the population is increased near 3% annual, are shown in Table 1.

Infrastructure Projects

The Urban Management Plan for El-Carmen City 2009-2015 (IMPLAN, 2009) also contains a set of road infrastructure projects for the future; they are shown in red colour in Figure 7.

The most significant projects are the following: a) two bridges on the rivers (Arroyo-Grande and Corregidora) and the extension of Boquerón-del-Palmar street; b) a tunnel under the landing strip of the airport; c) a new highway on the South (South Beltway), which includes a segment skirting a mangrove area and a segment on the lagoon; d) a new street on the northern skirts of the airport (North Street); e) a new road which is a half-circuit in the eastern part of the island (Orient Circuit); and f) a half-circuit beltway, which includes a segment skirting the beach and other skirting the lagoon, and a segment on the extreme eastern part of the future urban area (Costera).

Some of these road projects could be useful for improving traffic conditions, but others could worsen the situation.

Figure 5. Map of the Urban Management Plan for El-Carmen City 2009-2015 (IMPLAN, 2009)

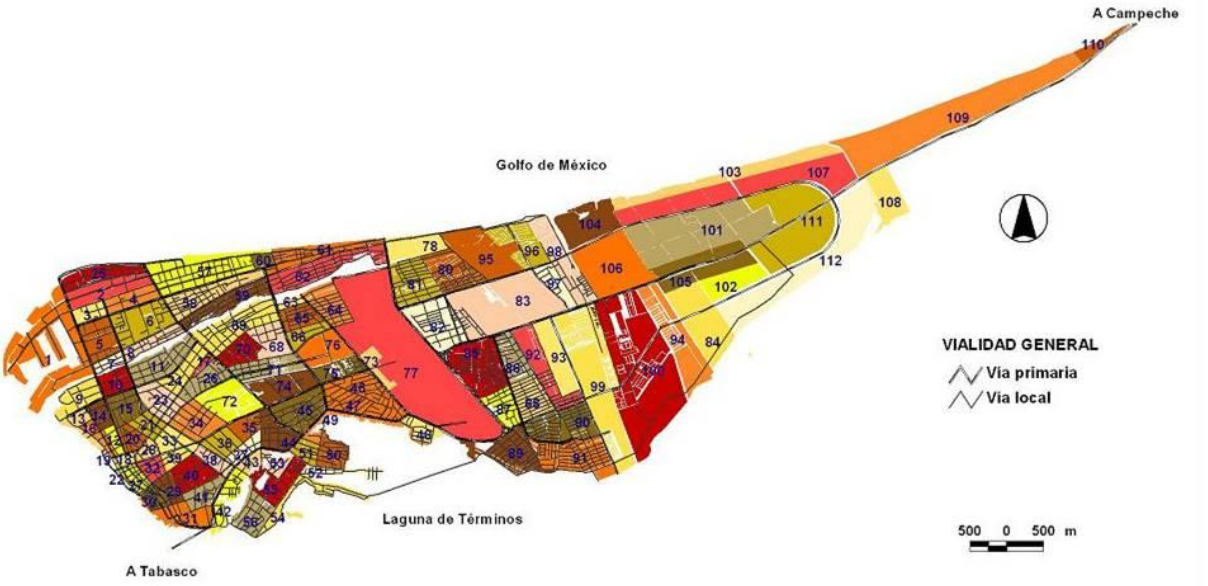

Figure 6. Traffic Attraction Zones (TAZ) for a future scenario

Table 1. Projections for population and housing projections of El-Carmen City (IMPLAN, 2007)

Year	Population	Housing
2005	151,452	39,698
2006	156,366	41,487
2007	161,331	43,355
2008	166,347	45,212
2009	171,413	47,126
2010	176,532	49,071
2011	181,690	51,014
2012	186,874	52,999
2013	192,082	54,948
2014	197,314	56,967
2015	202,562	58,978

Figure 7. Road infrastructure projects

"SPLIT BRAIN" DIAGNOSTIC

Depending on the degree of the split brain, the result of a callosotomy could be that (Gazzinaga, 2006): a) when communication between the two sides of the brain is inhibited, conflicting hemispheric desires or opinions can cause patients to exhibit some strange behavior; the patients give evidence of having two differing minds; and b) when the information transfer between hemispheres is reduced, i.e. the hemispheres are not completely disconnected, the right hemisphere can inject ideas into the left through the brainstem, hence patients experience these communications as unexplainable hunches from the unconscious.

El-Carmen City has severe communication problems between its two parts (eastern and western parts); it is similar to a partial callosotomy patient.

Due to the hemispheres specialization, when the right hemisphere of a split brain patient see an object, the patient can not find the words for naming it because the right hemisphere is non-verbal, then he tries communication with the left hemisphere, but it is difficult.

Similarly, El-Carmen City has two specialized parts, where the eastern part is the almost non-jobs-or-services part (due to its land-use). Hence, trips from the eastern part of the city search to reach the other side, where jobs and services exist, but transportation (communication) is difficult.

In order to improve communication, the government try to connect the eastern and western parts by means of several projects (some of them seem irrational). Among the projects are a tunnel under the airport landing strip of the airport, water way passenger transportation, a BRT, three "isolated" bridges proposed by PEMEX, and a set of infrastructure modifications included in the Urban Management Plan for El-Carmen City 2009-2015.

VEHICLE FLOW ESTIMATION

We estimate the flows on the arcs of the network, for each mode (car, taxi, bus, minibus, truck), by means of a multi-class traffic assignment model, which is solved by means of a cyclical procedure, where a traffic assignment problem for one mode, is solved in each cycle, assigning a portion of the trips of such mode (Lozano et al, 2009). This procedure was applied using a set of base origin-destination matrixes, one for each mode, obtained by means of sampling (interviews) and traffic counts in 22 points.

Several scenarios which consider the different road projects, for the current time and for a future short term, were generated and analyzed (Lozano et al, 2009).

Traffic Counts

The characteristics of the obtained traffic counts are the following:

- In each traffic count point, the number of vehicles on each movement was obtained for 15 minutes periods.
- The location of traffic count points are shown in Figure 8.
- The classification of vehicles is the shown in Table 2.
- Three time periods were considered, morning (6:00am-9:00am), afternoon (1:00pm-4:00pm) and night (6:00pm-9:00pm).

Based on traffic counts information and field work, the rush hours for the city were identified: 7:00am-8:00am and 1:45pm-2:45pm.

The flows of the two points belonging to the urban highway and the collector street, which are respectively on the northern and southern sides of the airport, have the following behaviour:

- The flow for the former point is composed of 72% cars, 12% taxis, 7% motorcycles, 4% minibuses, 2% buses, 2% non-articulated trucks and 1% trailers trucks. Its highest volume is obtained for the period 7am-8am (over 5,000 vehicles per hour).

- The flow for the latter point is composed of 64% cars, 13% minibuses, 9% taxis, 8% motorcycles, 3% non-articulated trucks, 2% buses and 1% trailers trucks. Its highest volume is obtained for the period 6:45am-7:45pm (over 1,900 vehicles per hour).

Remember that the number of lanes is four and two, respectively for the urban highway and the collector street.

Figure 8. Location of traffic count points

Table 2. Type of vehicles considered in traffic counts

Classification	Type of Service	Type of Vehicle
BC	Private	Bicycles
M		Motorcycles
A		Cars
B1	Public	Minibuses
B2		Buses
TX		Taxis (or minivans)
MC	Freight transportation	Articulated Trucks
CU		Non articulated trucks
CA		Trailers
CA2		Double trailers

Base O-D Matrix

A sampling was carried out in order to know the trips' characteristics, for trips in motor-vehicles with origin and destination in the TAZs.

Over 1,600 questionnaires were applied to public transportation users and near 400 to drivers of particular cars, taxis and trucks (on the street), during the following three periods: 6am-9am, 1pm-4pm and 6pm-9pm. Such periods included rush hours, obtained with base on traffic counts. Additionally, near 700 questionnaires were applied to people at home.

The obtained sampling information let us to know the characteristics of trips in El-Carmen City, i.e., their origins, destinations, transportation modes (cars, taxis, minibus, bus and trucks), etc. This information was processed to obtain the number of trips between each origin-destination (O-D) pair, for each transportation mode at rush hours (7:00am-8:00am and 1:45pm-4:45pm).

Later, trips information was expanded according to the number of vehicles obtained by traffic counts as well as demographic and socioeconomic data, obtaining an O-D matrix for each mode and each rush hour.

These matrixes were used as base O-D matrixes for estimating vehicle flows on the road network of El-Carmen City. Figure 9 shows the main desire lines during the morning rush hour (7:00am-8:00am), for cars. Note that, a large amount of trips goes from the eastern part to the western part of the city.

Hence, many people need to travel between the two parts of El-Carmen City. This need could be increase in the future when the eastern part of the island will be urbanized.

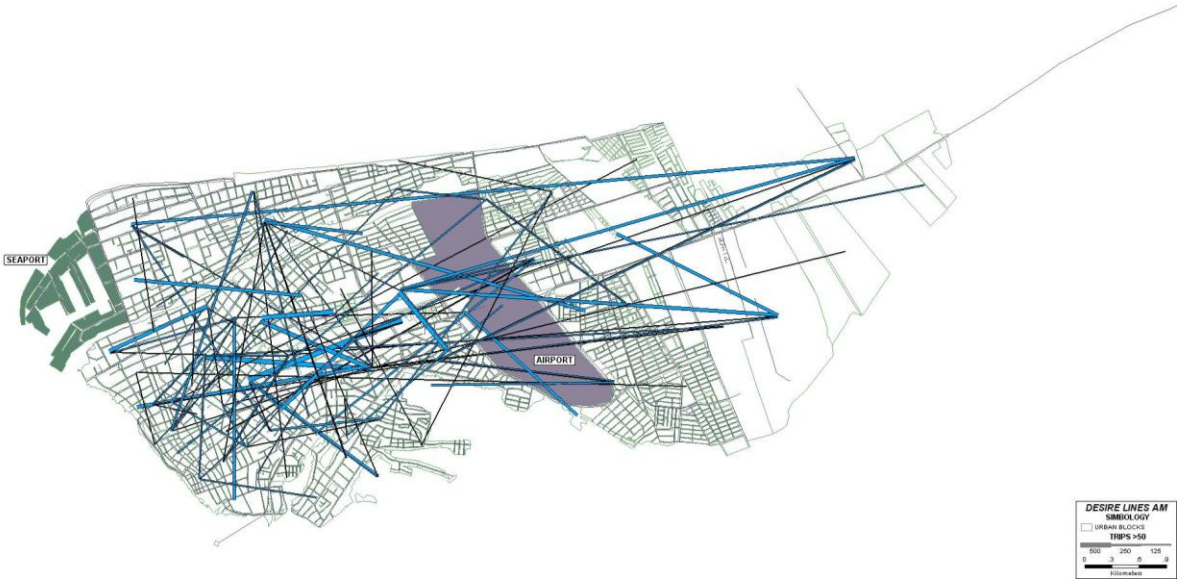

Figure 9. Desire lines during morning rush hour, in El-Carmen City

Flow Estimation Procedure

Based on the physical characteristics of each road segment, a capacity and a free-flow speed (without congestion) were assigned to them. Such information was used to estimate vehicle flows on each arc of the network, considering congestion. Estimation required information of seed or base O-D matrixes for each mode (five classes were used) as well as traffic counts for the chosen rush hours.

The flow estimation was made by means of an algorithm for the Multimodal or Multiclass User Equilibrium problem (Lozano et al, 2007; 2008).

In each algorithm' iteration, a User Equilibrium (UE) sub-problem was solved for each vehicle type. UE 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).

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

The objective of the first stage of the process was to estimate, for each vehicle type, an O-D matrix from a seed O-D matrix and traffic counts for such vehicle type.

In turn, the estimated O-D matrixes were used to estimate vehicular flow on the arcs of the network, considering that all of the types of vehicles travel simultaneously.

Hence, the cited algorithm allows estimate flows on each arc of the network for each vehicle type, considering that flow depends on congestion. The procedure was generated as a sub-routine and the results were displayed using TransCad©.

Scenarios for the Present Time

For the present time, the current scenario and seven alternative scenarios (called from 0 to 6) which include changes in the road network, were analyzed.

Current Scenario represents the situation in year 2008, when information was obtained.

Scenario 0 considers three projects proposed by PEMEX: two bridges on the rivers (Arroyo-Grande and Corregidora) and the extension of Boquerón-del-Palmar street.

Scenario 1 includes a modified version of the Scenario 0 projects, and direction changes for several streets in downtown. Such direction changes are oriented to facilitate a fast entrance and exit to/from downtown reducing the number of movements in street's intersections.

Scenario 2 includes a modified version of the Scenario 0 projects (the same of Scenario 1), and other direction changes for several streets in downtown.

Scenario 3 considers a modified version of the Scenario 0 projects (the same of Scenario 1), including an additional extension of Boquerón-del-Palmar street, plus the tunnel project which pass under the airport.

Scenario 4 includes the direction changes for several streets in downtown, which are considered in Scenario 1, plus the original extension of Boquerón-del-Palmar street.

Scenario 5 considers the following: the direction changes for several streets in downtown, which are considered in Scenario 1; the original extension of Boquerón-del-Palmar street; the new highway in the South (South Beltway); the new street on the northern skirts of the airport (North Street); and the new road which is a half-circuit in the eastern part of the island (Orient Circuit). The introduction of the South Beltway includes the Arroyo-Grande Bridge.

Finally, Scenario 6 includes all of the changes considered in Scenario 5, plus the prohibition of freight trucks on the urban highway.

The comparison of the estimated flows, for Current Scenario and Scenario 0, indicates that they are so similar for the morning and afternoon rush hours. This means that the proposed three projects (Arroyo-Grande Bridge, Corregidora Bridge and the extension of Boquerón-del-Palmar street) do not contribute to significantly improve the flow in El-Carmen City. Only the extension of Boquerón-del-Palmar street is used during the morning rush hour.

The comparison of the estimated flows, for Scenario 0 and Scenario 1, clearly indicates that Scenario 1 is better, especially in downtown. The improvement is because the vehicles can arrive at their destination in a more direct way, as a consequence of the direction changes of several streets in downtown.

The comparison of the estimated flows, for Scenario 0 and Scenario 2, also indicates that Scenario 1 is better, especially in downtown. The improvement is also because vehicles can arrive at their destination in a more direct way, as a consequence of the direction changes of several streets in downtown.

However, the comparison of the estimated flows for Scenario 1 and Scenario 2 indicates that they are almost equal but Scenario 1 is a little better. Until now, Scenario 1 is the best and hence the following scenarios are based on it.

The analysis of estimated flow for Scenario 3 indicates that the tunnel is fairly used at rush hours. Given that the tunnel is connected to the highway in the eastern part of the city, a bottleneck is formed from such intersection; similarly, a bottleneck is formed on the other side of the tunnel on an arterial street. The congestion of the bottlenecks is propagated to the nearby streets. Figure 10 shows estimated flow for Scenario 3.

The comparison of the estimated flows for the Current Scenario and Scenario 4 indicates that Scenario 4 is better, especially in downtown (see Figure 11). The reason is the direction changes of several streets. The extension of Boquerón-del-Palmar street gets some trips, specially at the morning rush hour.

The comparison of the estimated flows for Scenario 4 and Scenario 5 indicates that important flow is got by the following roads: the new South Beltway, especially in the segment on the lagoon; the new North Street; and an arterial street on the north, which is parallel to the beach.

Finally, the comparison of the estimated flows for Scenario 5 and Scenario 6 indicates that when freight trucks are prohibited on the urban highway, South Beltway and Orient Circuit are more used (see Figure 12).

Scenario 6 is the most appropriate scenario because it presents a better flow distribution, especially in the eastern area, where South Beltway and Orient Circuit capture some trips (which can be in-transit or local trips); otherwise, these trips would be added to the flow on the highway, especially during the morning rush hour. This also would be an advantage in the future, when the city will grow on the eastern part.

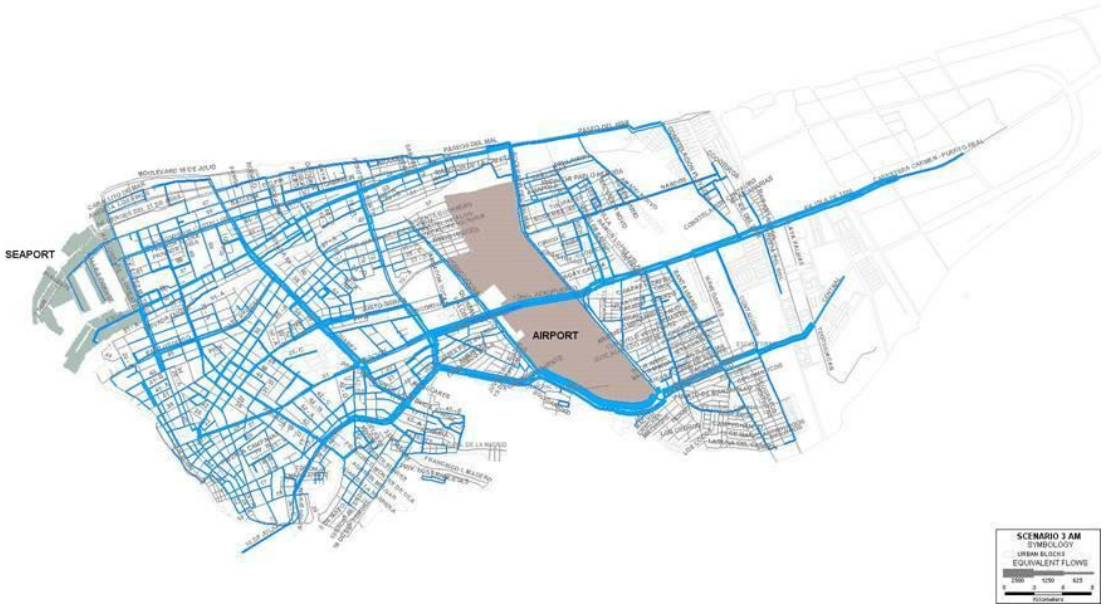

Figure 10. Estimated flow for Scenario 3 at the morning rush hour

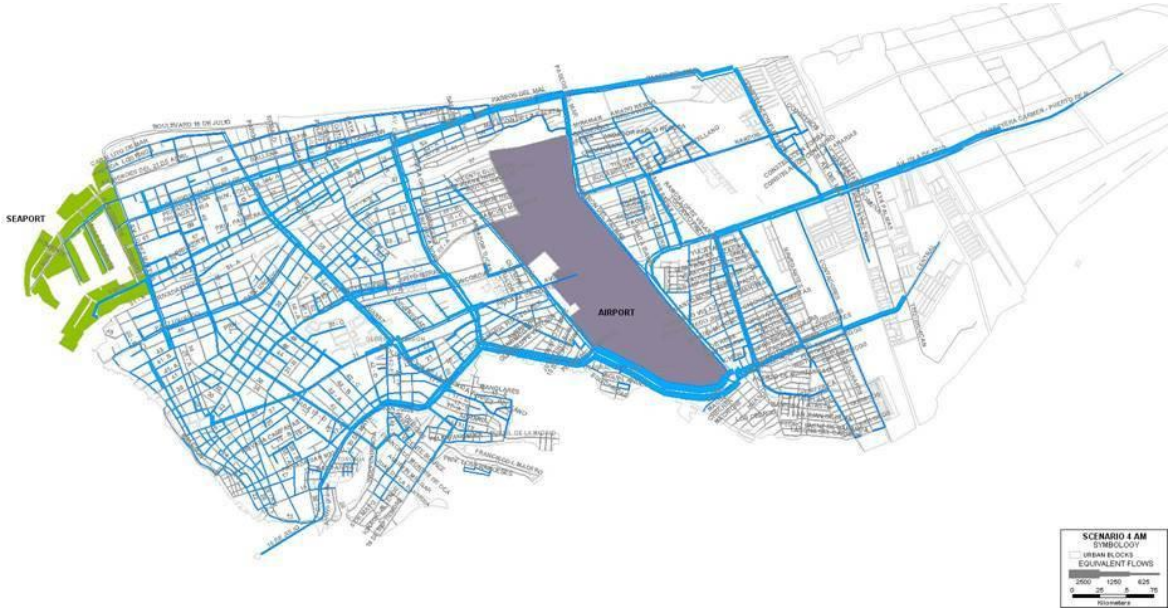

Figure 11. Estimated flow for Scenario 4 at the morning rush hour

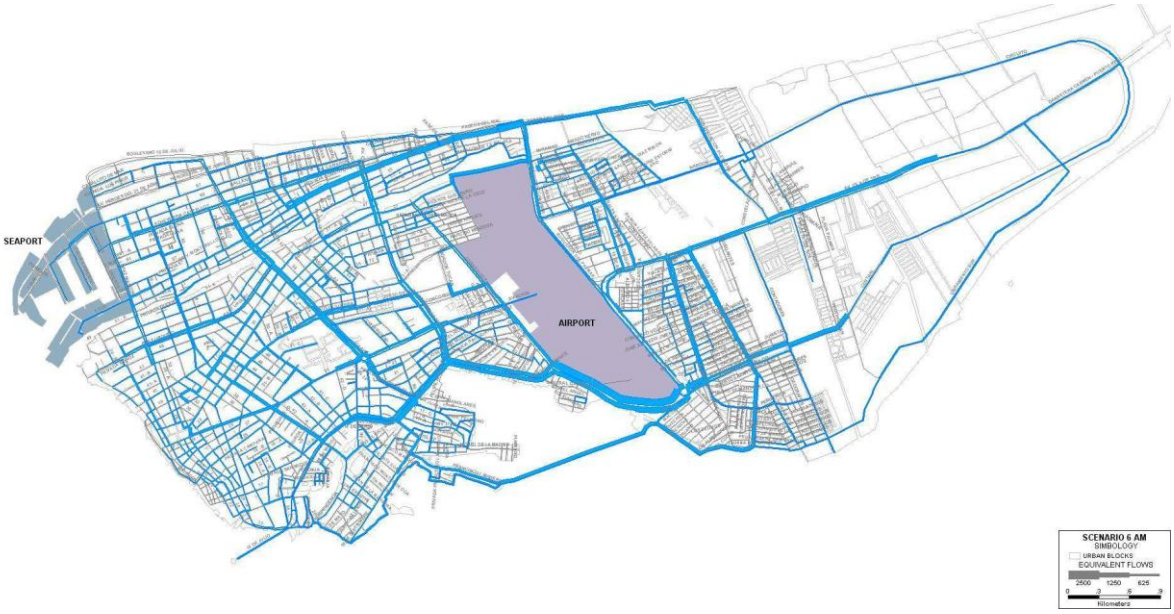

Figure 12. Estimated flow for Scenario 6 at the morning rush hour

Scenarios for a Future Time

Population increase for period 2005-2008 is near 10%, while for period 2008-2014 is near 20%. Regrettably, there is not information on the population increase in each zone. Hence, in order to generate a future horizon, the following assumptions were considered: the 10% population's increase is concentrated within the currently urbanized areas, while the 20% population's increase is distributed in the future urbanization areas according the Urban Management Plan for El-Carmen City 2009-2015. Floating population trips are 15% of the total trips, for both current and future horizons.

Several scenarios for the short term, considering a population increase by 20%, were generated (Lozano et al, 2009). These scenarios took into account the land-use changes in the eastern part of the city (De la Barra, 1989; Wegener and Franz, 1999). Hence, the future trips considered that the territory had been modified according to the Urban Management Plan, which proposed several land uses in the eastern part of the city (see Figure 5). Future O-D matrixes were obtained with base on the current O-D matrices and the land-use changes in the eastern territory.

The future scenarios are described as follows:

1. Scenario I is similar to the Current Scenario but considers future trips.
2. Scenario II is similar to the Scenario 4 but considers future trips.
3. Scenario III is similar to the Scenario 6 but considers future trips.
4. Scenario IV is similar to the Scenario III but includes the half-circuit beltway.

For Scenario I and Scenario II, the existence of an urban growth in the east area without having alternative roads for crossing between East and West, makes that the two existing connection roads get important flow and congestion, which is propagated upstream and to the streets in intersections. The direction change of the streets in downtown is not enough to significantly improve the flow movement in that area.

The comparison of the estimated flows for Scenario II and Scenario III indicates that Scenario III is much better in almost any place of the city.

Scenario III and Scenario IV offer several alternatives for trips between the eastern and western areas, which contributes to distribute flow among several pathways and consequently to improve the flow movement in the network. South Beltway and the North Street are quite used as well as the Orient Circuit (probably by local trips).

The comparison of the estimated flows, for Scenario II and Scenario III, indicates that they are similar. The main difference is that the Orient Circuit, the street on the beach and the eastern segments of the highway are more used in Scenario IV.

Therefore, Scenario IV has the best flow movement for the trips of a future horizon. It is because this scenario provides different alternative pathways for trips between the eastern and western parts of El-Carmen City. Scenario IV is shown in Figure 13.

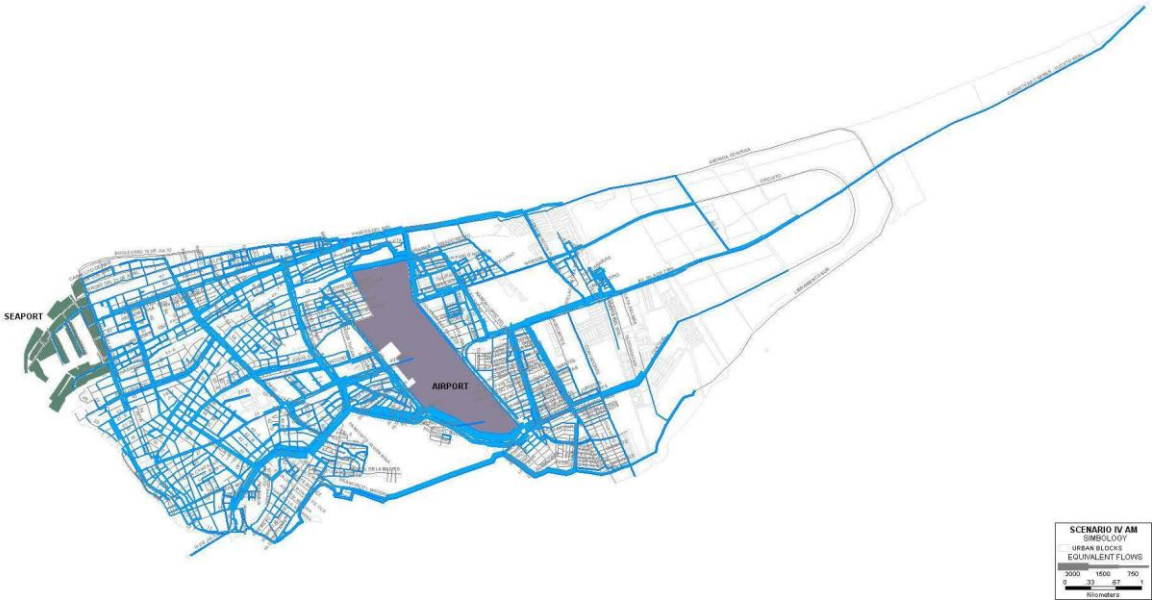

Figure 13. Estimated flow for Scenario IV at the morning rush hour

"SPLIT BRAIN" TREATMENT

The treatment for a split-brain city is the following:

a) Improving connection between the two parts of the city (two hemispheres).

b) Trying that the eastern part (right hemisphere) gets some specialization corresponding to the western part (left hemisphere). In some patients, after a period, certain specializations of a hemisphere are learned by the other hemisphere. For a city, it means land-use changes. For El-Carmen City, it is recommended to promote land-use which is linked to jobs and the satisfaction of services and commercial needs of people, in order to diminish the connection need to the other part of the city.

In split brain patients, connections at the back of the brain alone are enough to integrate both human minds. Split-brain patients could be manipulated into displaying two independent cognitive styles (two brains); however the underlying opinions, memories, and emotions were the same.

In the same way, El-Carmen city could have two almost independent sub-cities but with the same idiosyncrasy, problems and government.

An additional recommendation is to improve the internal communication of each side of the city.

The traffic analysis allowed us to obtain interesting results, on how to improve the communication or to reduce the needed of it in El-Carmen City, and discard some emblematic projects which did not consider the two brains of the city. The resulting recommendations for the current time, which can be quickly carried out, are described below.

An improvement of the current flow movement in downtown can be obtained by means of direction changes of some streets, and parking prohibition on those streets where public transportation routes exist in order to obtain at least two free lanes.

The changes of street directions imply changes in the public transportation routes. These routes must be changed according the following: to satisfy demand trips, to reduce congestion in down town, to avoid redundant routes, to pass routes on appropriate streets and to avoid the unnecessary turns. Although, these changes would move away (one to four blocks) people from their habitual stops, they would contribute to reduce congestion in downtown. Additionally, it is recommended that public transportation has far-from-corners fix stops.

Signing has to be improved; the use of official restrictive and informative signing is recommended.

Traffic lights must be synchronized. It is especially important on the urban highway, which must have priority cycles.

Also, it is necessary to promote the increasing of the number of public parking lots in downtown.

Regarding land-use, the recommendations are the following: a) in order to reduce the number of trips between the eastern and western areas, it is necessary that the eastern area has sites where working, shopping, going school, etc; and b) in order to preserve the continuity of the current streets in the eastern area, it is necessary do not allow the establishment of "superblocks" with a single entrance.

For the future horizon, some measures must be carried out in several stages. Among these, the land-use measures are very important because they are directly related with the future traffic. The planning and control of urban growth is very important because it directly rebounds on the number of trips and available infrastructure for them.

For example, a corridor must be composed of segment with similar characteristics, otherwise bottlenecks will be generated; and it does not must finish in a block or superblock. These problems are common in the western part of the city, but they does not must repeated in the eastern part.

For the design of the urban road network, one must to take into account that less congestion problems are generated when several alternative paths exist between each O-D point. The recommendation is to try to distribute traffic among the largest possible number of alternative paths. An opposed example is the traffic concentration produced by the tunnel (under the Airport) which has exits toward important congested streets.

Scenario IV was the best scenario for the future time, mainly because it provides more alternating paths for trips between the eastern and western parts of El-Carmen City. It is recommended then, to carry out the road projects of this scenario according the following order:

a) The direction changes of some streets in down town. This change could be immediate.

b) The North Street (a new street on the northern skirts of the airport) and the improvement of the characteristics of its adjacent streets.

c) The South Beltway (a new highway in the South which includes a segment skirting a mangrove area and a segment on the lagoon), including the Arroyo-Grande Bridge. This highway must have the appropriate geometric characteristics for the movement of large trucks and trailers as well as few connections to the urban network.

d) The prohibition of freight trucks on the current urban highway. This measure would be carried out when the South Beltway is available.

e) The Orient Circuit, a new road which is a half-circuit in the eastern part of the island. It is necessary to protect the areas where the Orient Circuit will be built (otherwise these areas will be occupied), and start the building on the northern side.

f) The extension of Boquerón-del-Palmar street.

g) The Costera Avenue, which is a half-circuit beltway that includes a segment skirting the beach and other skirting the lagoon, and a segment on the extreme eastern part of the future urban area. This road will be more and more important, as the urbanization goes growing in the eastern part of the city.

CONCLUSION

A traffic analysis was made for El-Carmen City. A funny comparison of a split brain patient and a split island-city was presented. It shown that, the network of the brain and a road network have some similitude related to communication problems, and a treatment for a split brain patient also can be useful for a split brain city.

Traffic analysis allowed the identification of different solutions to improve the connection between the eastern and western parts of the city, or to diminish the need of connection.

An algorithm for the multiclass traffic assignment model was used for obtaining estimated flow on each arc for each transportation mode. This information was very useful for the identification of the freight transportation flows. A large amount of freight flow corresponded to in-transit trips in the island; hence they can be sent to the new South Beltway.

The analysis of current and future scenarios allowed "prove" the convenience of several road projects, discarding some of them. Additionally, it was possible to propose a set of recommendations to be carried out as immediately as in several future stages. These recommendations are mainly related to road infrastructure, public transportation and land-use management.

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