A GIS Model of the National Road Network in Mexico

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Abstract

This paper describes a benchmark methodology for building a GIS model of the National Road Network in Mexico. A model of the road network is useful because it can help to calculate the shortest route between any two locations linked to the road system. The model estimates an average speed for every section in the network according to its hierarchy, regional location, toll status, and administration. Optimal routes can be estimated in terms of a time-minimisation criterion. The paper presents a statistical test that shows that the model presents a small bias of +6 percent in comparison to observed transit times of the Ministry of Transport. This bias can be fixed using a linear transformation of estimated time of transit.

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1. Introduction

In this paper, we present a methodology for building a GIS model of the National Road Network in Mexico (NRN). The resulting model can be used to estimate optimal routes between any two nodes within the network timesavings using as optimisation criterion. The model is tested using observed data from the Ministry of Communications and Transport in Mexico (SCT), showing that it has a small overall bias of +6 percent which can be fixed using a linear transformation of estimated time of transit.

The model uses cartographic data from the Topographic Digital Dataset (TDD), published by the National Institute of Statistics, Geography, and Informatics (INEGI) in 2000. This dataset includes comprehensive cartographic data of the National Road Network. The dataset classifies each road on the network according to the number of lanes, whether it is a toll or a free road, whether the federal or a state government administrates it, and whether the road is paved or unpaved. The dataset also includes the most important ferry routes and complete information on the rail network.

SCT, through the Administration of Federal Roads and Bridges (CAPUFE), offers a service on its website, which traces routes between the most important cities in the country. The system, called “Traza tu Ruta”, provides the user with information on the shortest route between any two cities including a description of the route, its total length, and the estimated time of transit. The data is used in the present study to estimate the average speed in each sections of the road network.

This paper is divided in 6 sections. Section 2 presents the hierarchical classification of the roads on the transport network. Section 3 includes a description of the structure of the road network for each macroregion in the country. Section 4 presents the methodology that was used to allocate an average speed for each section on the network and section 5 presents a statistical test of the accuracy of the model. Finally, section 6 presents some final remarks.
2. Hierarchical Classification of the National Road Network

According to SCT, the NRN comprises 14 national road corridors with a total length of 17,359 km. The national corridors connect the most important cities in the country across the 31 states and the Federal District. The corridors include 6,630 km of four-lane roads (38 per cent of the total length) and 4,976 km of toll highways (28 per cent of the total length). The national corridors are managed by the Federal Government.

The subnetwork is the higher hierarchy in the model and is shown in Figure 1.

A secondary network connects inner cities with the main corridors and several bridgelines between the main corridors and feeders. This subnetwork has an extension of 69,744 km and it includes both federal and state roads. The length of the network administrated by state governments is 39,635 km, representing 56 per cent of its total length. Almost 95 percent of the secondary network comprises two-lane roads; however, it also includes 1,760 km of one-lane roads, which are mainly located in Yucatan State. The secondary network is almost exclusively free; however, it also includes 969 km of toll roads. The road network is completed by 90,965 km of unpaved paths. It comprises 14,744 km and 39,140 km of two and one lane unpaved roads respectively.

Finally, the network includes two main ferry routes connecting the Baja California Peninsula with the main continental landmass (La Paz-Mazatlan, and Santa Rosalia-Guaymas), and the Caribbean islands of Cozumel and Isla Mujeres with the Yucatan Peninsula.
3. Regional Description of the National Network

This section, presents a description of the NRN. In order to simplify the analysis we divide the country into eight macroregions following Bassols-Batalla (1993). These regions are: I Northwest, II North, III Northeast, IV West-Central, V Central, VI South, VII East, and VIII Yucatan Peninsula. The regions do not strictly follow the political division of the country, so some states overlap through two or more regions. Bassols-Batalla (1993) presents a secondary regionalisation of the country in 134 microregions. Most of these regions lay completely within the limits of the eight major regions, with three important exceptions: The Huastecas, which overlaps regions III and VII, the Tehuantepec Isthmus, which overlaps regions VII and VIII, and the Sierra Madre Occidental, which overlaps regions I and II. Bassols-Batalla macroregions are shown in Figure 2.

3.1. Region I Northwest

Region I is crossed from north to south by national corridors II and XIV. The region can be subdivided in two main areas: the Baja California Peninsula and the continental landmass comprising the states of Sonora and Sinaloa. The Baja California Peninsula is crossed by corridor XIV, a two-lane paved road that connects almost all the cities in the region. In practice, all the important urban settlements in this area are connected to corridor XIV.

In the continental landmass, the coastal cities of Sonora and Sinaloa are connected to corridor II. The only part in this area that is not covered by this road is east Sonora, a mountainous region. Several feeders connect towns in the mountains to corridor II. There are two federal bridge lines connecting corridors II and III in the macroregion. The first one runs across the US Border and the second one –not completed yet- is supposed to connect the cities of Chihuahua and Hermosillo across the Tarahumara Mountain Range. Macroregion I is shown on Figure 2.

3.2. Region II North

The region is crossed in north south direction by corridors II and III and from east to west by corridor IV. The main cities of the states in this region are located close to
these corridors. In the state of Chihuahua, corridor II connects the capital of the state with the northern border cities. Almost all the western part of Chihuahua State lies on the Tarahumara Mountain Range, where road infrastructure is poor. A circuit in this zone connects the most important cities in the Tarahumara, where Ciudad Cuauhtemoc is the most important city. There is a secondary road, which connects the cities in the southern part of the state among them; however, no primary road connects these cities with either Sonora or Durango States.

In Coahuila State the population is highly concentrated in cities located along corridor III and the metropolitan zone of Torreon. A federal bridgeline connects corridors III and IV through the central plateau of Coahuila. Several unpaved roads connects the towns in this area to this road. Only one sate feeder connects inner northern Coahuila to corridor III. However, there are no urban settlements in this area. In the state of Durango two federal feeders connect the capital with the Durango Mountain Range, a predominantly mountainous area. An alternative federal road runs parallel to corridor III. In the state of Zacatecas two state bridgelines connect the cities of Fresnillo and Saltillo. In general terms the most important cities in the State are connected directly to corridor IV (Figure 4).

3.3. Region III Northeast

National corridor II, III, and IV cross the region both in a north-south and east-west direction. Several state bridgelines connect the three corridors among them. On the other hand there is a federal feeder that connects the northern border to the main network. Finally, a secondary federal road links all the border cities (Figure 5).

3.4. Region IV Central-West

The region is crossed longitudinally and transversally by corridors I, III, IV, and XII. Most of the important cities in the region are connected to these corridors or their feeders. The most important exception is the Jalisco coast, in the south westernmost part of the region. Only 2 federal feeders connects the ports of this area with the central plateau of the state. The coastal part of Nayarit is relatively well connected to the national network.
Several federal and state bridgelines connect the national corridors that cross the region with its central and eastern part making road density very high in this area. The road network in Region IV is well connected to the North East, North and Central macroregions, but poorly linked to the southern part of the country (Figure 6).

3.5. Region V Centre
The macroregion is crossed by corridors I, II, VII, X, XI and XII making it the densest in the country. The network follows a radial geometry having Mexico City as the central point. Corridor III, which ends in the border city of El Paso, is not part of the region; however, its start point is the central city of Queretaro, located north from Mexico City. Several federal bridgelines connect the national corridors among them and state feeders connect small villages in the central part of the region to the main lines. Road density –state and federal- is relatively low only in the northern part of Hidalgo State, and southern Puebla. The region is well connected to all the neighbouring macroregions (Figure 7).

3.6. Region VI South
The region is crossed from north to south by national corridors VII, VIII, and X. Corridor X connects the tourist port of Acapulco to the central plateau. Corridor VII connects the central valley of Oaxaca, the south port of the Tehuantepec Isthmus and the coast of Chiapas to the central plateau. Corridor VIII connects the coast of Michoacan State to Region IV. A federal two-lane road runs along the Pacific Coast from Mazatlan in Sinaloa to Tapachula in Chiapas, sharing some sections with the Tranisthmus Corridor (IX). Some federal secondary lines run parallel to the national corridors; however, there are very few feeders and bridgelines connecting these roads. It is worth mentioning that the mountainous area of the region is completely unconnected, so that for crossing the region in its west-east axis it is necessary to take either northern routes in the central plateau or the southern line that runs parallel to the Pacific Coast (Figure 8).
3.7. Region VII East
Region VII is crossed transversally by corridors VIII, IX, and X and longitudinally by IV and V. The northernmost areas are the Huastecas, which are crossed in their northern and eastern extremes by corridors IV and VIII. The roads of the primary network that lie on the Huastecas microregion are poorly interconnected: there are no federal bridgelines among these corridors, only unpaved roads.

The area between the Huastecas and the Papaloapan Basin is crossed by corridors V, X, and XII, which are the main routes between the Veracruz Port and Mexico City. The urban settlements in this area are well connected by numerous federal and state bridgelines, however only secondary bridgelines and no primary roads connect these cities to the main network.

Corridor V runs along the Papaloapan basin. Two secondary federal lines also cross the basin in the northern and southern section. The Tehuantepec Isthmus is connected only by the Tranisthmus Corridor (IX). Interior rural settlements in the isthmus are only connected to the main network through unpaved roads. The south-eastern area of the region, Tabasco, and northern Chiapas, are connected to corridor V and the Yucatan Peninsular Corridor (XIV). Central Tabasco is connected to its easternmost area by a federal feeder. A dense state subnetwork in central Tabasco links several villages to the capital (Figure 9).

3.8. Region VIII Yucatan Peninsula
A circuit formed by corridors V and XIV surrounds the Yucatan Peninsula. Almost all the cities in the states of Campeche and Quintana Roo are connected to these roads. Only the inner cities of Yucatan State are linked to the main peninsular roads through a smaller federal ring road. This circuit has as vertex the cities of Merida, Felipe Carrillo Puerto, and Tizimin, however there are several settlements that are not linked to any of these circuits. These villages are linked to the network by local state feeders. The network is relatively dense; however, despite being paved, most of the roads have only one lane (Figure 10).
4. Construction of the Model

A model of the road network is useful because it can help to calculate the shortest route between any two locations. The optimal route can be estimated in terms of a time-minimisation criterion as long as the model assigns an average speed to each section in the network. Therefore, it is necessary to estimate this variable.

The SCT published on its website, an estimated transit times for routes between selected cities in the country. For each route, average transit time is disaggregated by road section depending if the section is free or tolled. For each section, SCT data also mentions in which state does it lies. This data is extrapolated to the rest of the sections of the road network according the following criterion:

4.1. National Corridors
SCT presents estimated transit times for all the 14 national corridors in the network. For any corridor, the speed that is allocated to the sections lying in a particular state is equal to the average speed of all sections in that state. This assessment is performed separately for toll and free roads. The average speed of the neighbouring sections within the same corridor is allocated to sections lying in states that cannot be related to an specific state.

According to SCT data, the average speed of the national corridors is 107 km/h in toll highways and 85.9 km/h in free roads. Average speed does no present significant variations across toll highways; however, the variances across free sections are significant (Graphs 1 and 2).

4.2. Secondary Network
The secondary network is divided in eight major regions as presented above. In each region, we select a sample of routes and estimate their transit time and average speed according to SCT data. Since SCT does not present information for all the sections of the secondary network, we extrapolate the data from the sample to the rest of the roads in the region, assigning to each of them the estimated average speed of the routes in the sample.
For each region, we calculate the average speed and standard deviation. If in any region the standard deviation is higher than an arbitrary threshold, we split that region in smaller areas following the regionalisation proposed by Bassols-Batalla (1993) and assign to the new sub-regions the average speed of the sampled routes laying in its territory.

4.2.1. Sample
The criterion for selecting the sample tries to choose for each region, routes covering the maximum possible area. In particular, the criterion selects feeders crossing through the longest axis of a region that connects the interior cities of a region with the national corridors, Bridgelines that connect the corridors that cross a region; secondary lines parallel to a national corridor; and state circuits connecting dense populated areas.

The sample for each region is described below:

4.2.1.1. Region I Northwest
The sample in this macroregion includes a federal and a state feeder that connect east Sonora with corridor II. It also includes a north-south bridgeline along the Sonora mountain range in its longest axis. The sample also includes two feeders between coastal Sinaloa cities and the Sinaloa Mountain Range, as well as a feeder in Baja California state. Since almost all the cities in Baja California Peninsula are connected to the Tranpeninsular corridor, no additional sample was taken.

4.2.1.2. Region II North
The sample of routes includes the following: a federal feeder that starts in the northern border and ends in central Chihuahua, the Monclova-Torreon bridgeline in Coahuila, a feeder between sierra de Durango and Durango’s capital city, and two state feeders in Zacatecas. It also includes a free federal road between Durango and Chihuahua. The Durango and Tarahumara Mountains are not connected, however the route Chihuahua-Sonora crosses this range and it is included as a separate observation in the sample.
4.2.1.3. Region III Northeast
The sample includes a federal bridgeline that links all the border cities in the region, a central bridgeline that connects central Nuevo Leon with the Gulf of Mexico, and two feeders that link Ciudad Victoria, in Tamaulipas with the northern part of The Huastecas and the central part of the state.

4.2.1.4. Region IV Central-West
It includes the coastal line of Jalisco and the main feeder between Guadalajara nodal zone and south coast of Jalisco State. It also includes four principal bridgelines: Uruapan-Cd Guzman (between the west and east section of corridor VIII), Irapuato-Zamora (between corridors I and III), Silao-San Luis de la Paz (between corridors II and III), and Zitacuaro-Dolores (between corridors I and II).

4.2.1.5. Region V Central
The sample of secondary routes in this region includes a semiarc composed by all federal roads that surround Mexico City. The northern arc runs from Atlacomulco to Ciudad Sahagun, through Mexico and Hidalgo state. The south-western arc, continues from Atlacomulco to Izucar, through the states of Mexico, Morelos, and ends in Puebla. The eastern part of the arc is extended between Ciudad Sahagun to Puebla, in the sates of Hidalgo and Puebla. Finally, the southeast extreme of the arc is closed by corridor XI, a primary road, so it is not include, in the sample. The sample also includes a bridgeline between corridor V and XII in the south easternmost extreme of the region.

4.2.1.6. Region VI South
The sample includes the federal line, which runs along the Pacific coast between Manzanillo, and Tapachula, which lies in the states of Sinaloa, Jalisco, Colima, Michoacan, Guerrero, Oaxaca, and Chiapas. It also includes the route through the mountain range from Apatzingan, to Oaxaca, via Chilpancingo and Ciudad Altamirano, through the states of Michoacan, Guerrero and Oaxaca. It also includes three federal feeders that link the Pacific coast to inner Guerrero, northwest Oaxaca, and northeast Oaxaca. Finally, it includes two routes from the state of Chiapas, first
an interior semiarc, which links the inner cities in the state to the main network, and a
feeder which connects the southern border to national corridor V.

4.2.1.7. Region VII East
The sample includes the following routes: Tuxpan-Ciudad Valles, which is a
bridgeline that links corridors IV and VIII in The Huastecas microregion. In central
Veracruz, it includes a bridgeline between corridors V, X, and XII (these are, Perote-
Poza Rica, and Veracurz-Orizaba in Veracruz Sate). In the Papaloapan Basin it
includes two secondary federal lines that run along the section Puebla-Coatzacoalcos
of national corridor V (Sates of Puebla and Veracruz). In the Tehuantepec Isthmus it
does not include additional sample since all the settlements are served by corridor IX.
Finally, the sample has the route Escarcega-Tenosique-Villahermosa, and the route
Villahermosa-Paraiso-Chotalpa both in the sate of Tabasco.

4.2.1.8. Region VIII Yucatan Peninsula
In this region the sample includes tow routes: first Merida-Carrillo Puerto-Tizimin,
which is part of the inner circuit of the peninsula. In second place, it includes the route
Tikul-Dzilam Bravo, which is the longest route that links inner Yucatan State to the
northern coast of the peninsula.

4.2.2. Sub-Regional Variations
The estimated regional average speed exhibit important variations across regions,
with the South being the one with the slowest roads (68.7 km/h) and the Yucatan
Peninsula and the Northern region being the ones with the highest speeds (87.9 and
86.08 km/h). The speed variations -measured as standard deviation $\sigma[v]$- across
sampled routes in each region are low in all regions except for the South ($\sigma[v]=104$)
and the East ($\sigma[v]=35$). Variation in the Northwest region is also relatively high
($\sigma[v]=31.4$). However, when the route that crosses the mountain range of Sonora is
excluded speed variation takes a considerable lower value ($\sigma[v]=20.1$), as shown in
Graph 3.
The estimated average speed for each macroregion is extrapolated to all the roads located within their limits. However, given the sub-regional variations mentioned above, we follow a special criterion for the Northwest, the South, and the East (regions I, VI, and VII). This criterion is described below.

4.2.2.1. Region I Northwest
The route that connects central Sonora to the mountain range (Hermosillo-Sarihuapa) is excluded from the sample and the estimated average speed is allocated to all the roads in regions I, VI, and VII, except for those lying on the Sonora Mountain. A special region is formed by roads in the Sonora and Chihuahua Mountain. The average speed allocated to this special region is equal to the speed of the route connecting its extremes through its largest axis (Sarihuapan-Chuauhtemoc).

4.2.2.2. Region VI South
The region is subdivided in five areas. The first one is the Pacific coast, starting in the east in Manzanillo, Sinaloa and ending in Salina Cruz, Oaxaca. This special region extends to the north up to the southern part of the Sierra Madre Occidental. The average speed allocated to this area is equal to the speed of the Manzanillo-Salina Cruz route described above. Three areas are defined over the mountain zone of Guerrero and Oaxaca: Guerrero Mountain, West Oaxaca Mountain, and East Oaxaca Mountain. The average speed allocated to each of these regions is the same as in the routes that link the Pacific coast to the central plateau of Mexico. These include Iguala-Zihuatanejo, Izucar de Matamoros-Puerto Escondido, and Tuxtepec-Puerto Escondido. The average speed assigned to the northern area of Michoacan, Guerrero, and Oaxaca state correspond to the speed of the Apatzingan-Oaxaca route in Michoaca, Guerrero and Oaxaca States. It crosses the region from west to east through the northern extreme of the Sierra Madre. Finally, the average speed assigned to roads in Chiapas States is equal to the average of the routes connecting central Chiapas and the southern border.
4.2.2.3. Region VII East
The region is divided in three areas. The first one is central Veracruz, which covers
the area between the Huastecas and Xalapa, the second one is the Veracruz Mountain,
covering the area between Xalapa and Orizaba, the third one is the Papaloapan Basin.
and the State of Tabasco. Except for the last area, which is shared by Tabasco State,
the rest of the special regions lies completely within Veracruz State. Two additional
areas are considered. The first one is the microregion of the Huastecas, that extents
itself through the borders of Tamaulipas, Hidalgo, San Luis Potosi, and Veracruz. The
average speed for the roads on this region is equal to the route Tuxpan-Cd. Valles, via
Molango. The Tehuantepec Isthmus is the other special region, and the average speed
allocated to its roads is equal to the average speed of the Transisthmus Corridor (IX).

4.3. Unpaved Network
SCT does not provide any data about estimated transit time of unpaved roads in the
country. Only few small and remote settlements are connected to the main road
network exclusively through unpaved roads. Nevertheless, it is important to allocate
an average speed to the unpaved network in order to complete the model. Therefore,
each unpaved road is allocated a base speed as if it were a secondary road. The
average speed allocated is equal to a fraction of this base speed. In the model we
present this fraction is 20 percent.

4.4. Urban Zones
When a corridor or secondary road crosses a metropolitan area, average speed
decreases due to the congestion of urban roads. SCT publishes the average speed in
urban roads for selected cities. We select a sample of seven cities where this data is
available and we calculate an average speed of 51.6 km/h. Variations in urban speeds
across cities is very small ($\sigma[v]=16.12$).

We select 11 metropolitan areas with population higher than 800,000. These cities are
Mexico City, Guadalajara, Monterrey, Puebla, Ciudad Juarez, Tijuana, Leon, Toluca,
Torreon, San Luis Potosi, and Merida. We allocate an average speed of 51.66 km/h to
all paved roads that lie in the urban area of these 11 cities. Toll highways and unpaved
roads keep their original speeds.
4.5. Ferry Lines

The average transit time of each ferry line was taken directly from the local provider service provider’s internet website.

5. Estimated Speeds

According to the model, the estimated average speed on the national corridors is 89.3 km/h while on the secondary roads it is 75.19 km/h. The inter-state variations of this variable are considerable for both types of roads, with a standard variation of 59.0 and 42.1 for corridors and secondary roads respectively. The state with the lowest average speed (apart form the predominantly urban state of Mexico and the Federal District) is Oaxaca, followed by Puebla, Guerrero, and Veracruz. It is worth mentioning that road density is not necessarily low in these states, showing that this variable might not be the ideal proxy for measuring the effects of the road infrastructure in a particular geographic area (Table 1).

We test the accuracy of the model estimating the average transit time of a random sample of routes and comparing it to the transit time published by SCT. The sample considers 135 cities, which are the main settlement of regional capital of each microregion in the country as presented by Bassols-Batalla (1993), 20 international cargo ports, 21 northern-border crossing points, and four southern-border crossing points. The number of possible routes that can be traced between any of these nodes is 32,400, clearly illustrating the necessity of using sampling methods for testing the model. The selected sample includes 30 random routes, as described in Table 2.

We estimate the transit time for each route in the sample by two methods. The first one is the unrestricted optimal path, whose algorithm calculates the minimum cost between the two nodes, taking as impedance variable the transit time of each section in the network. The algorithm selects sections independently of their hierarchy. The second method uses a hierarchical algorithm. This method estimates the path with the smallest cost between any two nodes, selecting the road with the highest hierarchy when two or more options are available, independently of the cost. When only roads of the same hierarchy are available, it selects the road with the lowest impedance, in
this case, with the highest speed. The algorithm is heuristic and it does not calculate optimal routes. A characteristic of the hierarchical algorithm is that it does not necessarily trace a direct route for every two nodes in the network, so the complete set of routes has to be found using an application of the minimum path problem, in this case, the Dijkstra's algorithm. Despite its restrictions, the hierarchical algorithm may trace more realistic routes than an unrestricted algorithm.

The estimated transit times under the two methods are compared with the data of SCT. The comparison shows that the unrestricted model has an error of +6 percent while the hierarchical model presents an error of +10 percent. In absolute terms, the error of the unrestricted model is +37 min for the typical route, while the error for the hierarchical model is +1h 9 min. For the unrestricted model the estimated bias lies between +6 and +8 percent with a confidence interval of 95 percent. Since this error is estimated using a sample that is representative at national level, a linear transformation of the estimated time for any route can be used to generate completely unbiased results (Table 3).

The test shows that the unrestricted model is more accurate than the hierarchical model. This suggests that in this context it is not better to introduce a hierarchical algorithm for estimating realistic routes. Finally, the test shows that the model emulates the data published by SCT reasonably well.

6. References

Bassols-Batalla, A (2002). “Geografía Socioeconómica de México”. Trillas, Mexico
Appendix

In this appendix, we present the definition of average speed, speed standard deviation and its estimation.

Average speed is defined as total distance $S_T$ divided by the total time $T$ used for transiting that distance.

Equation (1) \[ E[v] = \frac{S_T}{T} \]

Average speed in the interval $\Delta S$ can be defined as follows:

Equation (2) \[ v_t = \frac{\Delta S}{\Delta t} \]

It is clear from Equation (2) that solving for $\Delta S$ and adding through $t$ allows average speed to be expressed as the weighted average of speed in the interval $\Delta S$.

Equation (3) \[ E[v] = \frac{\Delta t}{T} \sum v_t \]

Finally, we define speed variation as the square of the difference between the average speed in interval $\Delta S$ and average speed. Speed standard deviation is defined as the square root of the speed variation.

Equation (4) \[ \sigma[v] = \sqrt{\frac{\sum (v_t - E[v])^2 \Delta t}{\Delta t}} \]
Table 1. Average Speed by State
National Road Network Model

<table>
<thead>
<tr>
<th>Area (sq. km Thousands)</th>
<th>National Trunklines</th>
<th>Secondary Roads</th>
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<td></td>
<td>Length</td>
<td>Road Density</td>
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<td>17,332.72</td>
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1. Águascalientes
2. Baja California
3. Baja California Sur
4. Campeche
5. Coahuila de Zaragoza
6. Colima
7. Chiapas
8. Chihuahua
9. Distrito Federal
10. Durango
11. Guanajuato
12. Guerrero
13. Hidalgo
14. Jalisco
15. México
16. Michoacán de Ocampo
17. Morelos
18. Nayarit
19. Nuevo León
20. Oaxaca
21. Puebla
22. Querétaro de Arteaga
23. Quintana Roo
24. San Luis Potosi
25. Sinaloa
26. Sonora
27. Tabasco
28. Tamaulipas
29. Tlaxcala
30. Veracruz-Llave
31. Yucatán
32. Zacatecas
### Table 2. Accuracy Test Sample

<table>
<thead>
<tr>
<th>Route (Sample)</th>
<th>Distribution</th>
<th>Sample</th>
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<tr>
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### Table 3. Mean Differences between Models

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<td></td>
<td>Absolute</td>
<td>Percentage</td>
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<tr>
<td>Mean</td>
<td>0.63</td>
<td>0.06</td>
<td>1.16</td>
<td>0.10</td>
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<td>Satandar Deviation</td>
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<td>0.09</td>
<td>1.20</td>
<td>0.11</td>
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<tr>
<td>CV (Std.Dev/Mean)</td>
<td>1.43</td>
<td>1.42</td>
<td>1.04</td>
<td>1.03</td>
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Graph 1. Average Speed ($v$) on National Corridors. Toll

**Toll Trunklines**

Graph 2. Average Speed ($v$) on National Corridors. Free

**Free Trunklines**
Graph 3. Average Speed (v) on Secondary Network. Sample

Regional Network

<table>
<thead>
<tr>
<th>Region</th>
<th>Average Speed (km/h)</th>
<th>Standard Deviation (sd(v))</th>
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<td>IV - Centro Oeste</td>
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<td>VI Sur</td>
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<td>VII - Este</td>
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<tr>
<td>VIII Yucatan</td>
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</table>
Figure 1. National Corridors I
Figure 2. Macroregions

Macro-Region
I. North West
II. North
III. North East
IV. West
V. Central
VI. South
VII. East
VIII. Yucatan

Symbol
- Macro Region Limit
- Political Limit Between Region VI and VII
- State Limits

Kilometers
Figure 3. National Road Network: Macroregion I
Figure 4. National Road Network: Macroregion II
Figure 5. National Road Network: Macroregion III
Figure 6. National Road Network: Macroregion IV
Figure 7. National Road Network: Macroregion V

[Map of National Road Network in Macroregion V with cities and roads labeled.]
Figure 8. National Road Network: Macroregion VI
Figure 9. National Road Network: Macroregion VII
Figure 9. National Road Network: Macroregion VIII