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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 on 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's results have a small bias of +6 percent in comparison to observed travel times from the Mexican Ministry of Transport. This bias can be fixed using a linear transformation of estimated travel time.

Key words: GIS model, Mexican National Road Network, Mexico, optimal route, time-minimisation

JEL codes: R40, R41, R49

1 MEXICAN SUB-SYSTEM

This paper presents the methodology followed to build the North American GIS Road Network Model, a tool that can be used to estimate optimal routes between any two nodes within the network using travel times as an optimisation criterion. The model uses cartographic data from the Topographic Digital Dataset (TDD) and the Municipal Geo-Statistical Framework, published by the National Institute of Statistics, Geography, and Informatics (INEGI 2000a, 2000b). This dataset includes comprehensive cartographic data of the National Road System. It classifies each road 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.

The Secretary of Communications and Transport (SCT), through the Administration of Federal Roads and Bridges (CAPUFE), offers a service on its website that 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 travel time. The data is used in the present study to estimate the average speed in each section of the road network.

1.1 Hierarchical Classification of the National Road System

According to the SCT, the national road system in Mexico comprises 14 Federal Corridors with a total length of 17,356 km. The Federal 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 Federal Corridors are managed by the Federal Government. This subnetwork of Federal Corridors has the highest hierarchy in the model. It is shown as '*trunklines'* on Figures 1 to 8.

A secondary network connects inner cities with the main corridors and several local roads between the main corridors and their feeders. This subnetwork has an extension of 69,768 km and includes both federal and state roads. The length of the network administered 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 toll-free; however, it also includes 969 km of toll roads. The road network is completed by 90,965 km of unpaved roads. 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.

1.2 Construction of the Model

The objective of the model is to work as a tool to calculate the optimal route between any two locations, which is defined as the route which minimises travel time. In order to do this, the model needs to assign an average speed to each section of the network.

The SCT publishes on its website estimated travel times for routes between selected cities in the country. For each route, average travel time is disaggregated by road section depending on whether the section is toll-free or tolled. The data also includes the state where each section is. This data is extrapolated to the rest of the sections of the road network following a special criterion for each road hierarchy, which is explained below.

1.2.1 Federal Corridors

The SCT presents estimated travel times for all the 14 Federal Corridors on 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 the sections in that state. This exercise is performed separately for toll and toll-free roads. For sections that cannot be related to a specific state, the average speed assumed is that of the neighbouring sections within the same corridor.

According to SCT data, the average speed of the Federal Corridors is 107 km/h on toll highways and 85.9 km/h on toll-free roads. Average speed does no present significant variations across toll highways; however, the variances across toll-free sections are significant (Figures 9 and 10).

1.2.2 Secondary Network

The secondary network is divided in eight macroregions.[1] For each macroregion, we select a sample of routes and estimate their travel time and average speed according to SCT data. Due to the fact that the 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 macroregion, we calculate the average speed and standard deviation of its roads. If in any macroregion the standard deviation is higher than an arbitrary threshold, we split it in smaller areas following the NUTS3 division for Mexico as presented in the paper. To each of these regions we assign the average speed of the sampled routes in their respective territories.

a. Sample The criterion for selecting the sample was to choose for each macroregion, routes that cover the maximum possible area. In particular, we selected feeders crossing through the longest axis of a region, which typically connects the interior cities of a region with the Federal Corridors, local roads, which connect the corridors that cross a region, secondary lines parallel to a Federal Corridor, and state circuits connecting dense populated areas. The sample for each region is described below.

[1] Macroregions are as defined by Bassols-Batalla (1993, 2002).

i. Region I Northwest: The sample in this macroregion includes a federal and a state feeder, which connect east Sonora (S126) with the Federal Corridor II. In addition, it includes a north-south local road along the Sonora (S126) mountain range in its longest axis. The sample also includes two feeders between coastal Sinaloa (S125) cities and its mountain range, as well as a feeder in Baja California (S102). Due to the fact that almost all the cities in Baja California Peninsula are connected to the Federal Corridor XIII, no additional sample was taken.

ii. Region II North*:* The sample of routes includes a federal feeder that starts in the northern border and ends in central Chihuahua (S108), the Monclova-Torreon local road in Coahuila (S105), a feeder between sierra de Durango (S110) and its capital city, and two state feeders in Zacatecas (S132). In addition, it includes a free federal road between Durango (S110) and Chihuahua (S108). 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.

iii. Region III Northeast: The sample includes a federal local road that links all the border cities in the region, a central local road that connects central Nuevo Leon (S119) with the Gulf of Mexico, and two feeders that link Ciudad Victoria, in Tamaulipas (S128) with the northern part of The Huastecas (R1131) and the central part of the state.

iv. Region IV Central-West*:* The sample includes the coastal line of Jalisco (S114) and the main feeder between Guadalajara and the south coast of the state. In addition, it includes four principal local roads: Uruapan- Guzman (between the west and east section of corridor VIII), Irapuato-Zamora (between Federal Corridors I and III), Silao-San Luis de la Paz (between Federal Corridors II and III), and Zitacuaro-Dolores (between Federal Corridors I and II).

v. Region V Central*:* The sample of secondary routes in this region includes a semiarc composed of all the federal roads that surround the Federal District (S109). The northern arc runs from Atlacomulco to Sahagun, through Mexico (S115) and Hidalgo (S113) sate. The south-western arc continues from Atlacomulco to Izucar, through the states of Mexico (S115), Morelos (S117), and ends in Puebla (S121). The eastern part of the arc is extended between Ciudad Sahagun to Puebla, in the sates of Hidalgo (S113) and Puebla (S121). Finally, the southeast extreme of the arc is closed by corridor XI, a primary road, so it is not included in the sample. The sample also includes a local road between corridor V and XII in the south easternmost extreme of the region.

vi. Region VI South*:* The sample includes the federal line that runs along the Pacific coast between Manzanillo and Tapachula, and lies in the states of Sinaloa (S125), Jalisco (S114) Colima, (S106), Michoacan (S116), Guerrero (S112), Oaxaca (S120), and Chiapas (S107). In addition, it includes the route through the mountain range from Apatizingan, to Oaxaca (S120), via Chilpancingo and Ciudad Altamirano, through the states of Michoacan (S116), Guerrero (S113) and Oaxaca (S120). In addition, it includes three federal feeders that link the Pacific coast to inner Guerrero (S113), northwest Oaxaca (S120), and the northeast of the state. Finally, it includes two routes from Chiapas (S107), first an interior semiarc that links the inner cities in the state to the main network, and a feeder that connects the southern border to Federal Corridor V.

vii. Region VII East: The sample includes Tuxpan-Ciudad Valles, which is a local road that links corridors IV and VIII in The Huastecas microregion. In central Veracruz (S130), it includes a local road between corridors V, X, and XII (these are, Perote-Poza Rica, and Veracurz-Orizaba in Veracruz S130). In the Papaloapan Basin it includes two secondary federal lines that run along the section Puebla-Coaztacoalcos of Federal Corridor V (Puebla S121 and Veracruz S130). In the Tehuantepec Isthmus it does not include any additional road given that all the settlements are served by corridor IX. Finally, the sample includes the route

Escarcega-Tenosique-Villahermosa, and the route Villahermosa-Paraiso-Chotalpa both in the state of Tabasco (S127).

viii. Region VIII Yucatan Peninsula: The sample includes two routes: first, Merida-Carrillo Puerto-Tizimin, which is part of the inner circuit of the peninsula, and second, Tikul-Dzilam Bravo, which is the longest route that links inner Yucatan (S131) to the northern coast of the peninsula.

b. Sub-Regional Variations The estimated regional average speeds exhibit important variations across regions, with the South being the one with the lowest speeds (68.7 km/h) and the Yucatan Peninsula and the Northern macroregion being the ones with the highest speeds (87.9 and 86.08 km/h). The speed variations -measured as standard deviation σ_v- across sampled routes in each region are low in all regions except for the South (σ_v=104) and the East (σ_v=35). The variation in the Northwest macroregion is also relatively high (σ_v=31.4). However, when the route that crosses the mountain range of Sonora is excluded speed variation takes a considerable lower value (σ_v=20.1), as shown on Figure 11.

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 (macroregions I, VI, and VII). This criterion is described below.

i. Region I Northwest: The route that connects central Sonora (S126) to the mountain range (Hermosillo-Sarihuapa) is excluded from the sample and the estimated average speed is allocated to all the roads in macroregions I, VI, and VII, except for those located on the Sonora Mountain (R1100). 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-Chuahtemoc).

ii. Region VI South: The region is subdivided in five areas. The first is the Pacific Coast, starting in the east in Manzanillo and ending in Salina Cruz in Sinaloa (S125), 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 (S112) and Oaxaca (S120): Guerrero Mountain, West Oaxaca Mountain, and East Oaxaca Mountain. The average speed allocated to each of these areas is the same speed allocated to 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 (S116), Guerrero (S112), and Oaxaca (S120) corresponds to the speed of the Apatzingan-Oaxaca route. It crosses the region from west to east through the northern extreme of the Sierra Madre Mountains. Finally, the average speed assigned to roads in Chiapas (S107) is equal to the average speed of the routes connecting the centre of the state and its southern border.

iii. Region VII East: The region is divided in three areas. The first is central Veracruz, which covers the area between the Huastecas and Xalapa, the second is the Veracruz Mountains, which covers the area between Xalapa and Orizaba, and the third is the Papaloapan Basin and Tabasco (S127). Except for the last area, the rest of the special regions lie completely within Veracruz (S130). Two additional areas are considered. The first is the microregion of the Huastecas, which extends itslf through the borders of Tamaulipas (S128), Hidalgo (S113), San Luis Potosi (S124), and Veracruz (S130). The average speed for the roads in this region is equal to the average speed on 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 Federal Corridor IX.

1.2.3 Unpaved Network

The SCT does not provide any data on estimated travel 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 our model this fraction is 20 percent.

1.2.4 Urban Areas

When a corridor or secondary road crosses a metropolitan area, the average speed decreases due to the congestion on urban roads. The SCT publishes the average speed on 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 (σ_v=16.12).

We select eleven metropolitan areas with population higher than 800,000. These cities are Mexico City (R1126), Guadalajara (R1047), Monterrey (R1074), Puebla (1081), Ciudad Juarez (R1029), Tijuana (R1005), Leon (R1128), Toluca (R1055), Torreon (R1125), San Luis Potosí (R1091), and Merida (R1134). We allocate an average speed of 51.66 km/h to all paved roads that lie in the urban area of these eleven cities. Toll highways and unpaved roads keep their original speeds.[2]

1.2.5 Ferry Lines

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

[2] The territory for each metropolitan area follows the classification presented in the appendix.

1.3 Accuracy Test

According to the model, the estimated average speed on Federal Corridors is 89.3 km/h while on 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 from the predominantly urban state of Mexico S115 and the Federal District S109) is Oaxaca (S120), followed by Puebla (S121), Guerrero (S112), and Veracruz (S130). 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 road infrastructure in a particular geographic area (Table 1).

We test the accuracy of the model by estimating the average travel time of a random sample of routes and comparing it to the travel time published by the SCT. The sample is drawn from a population of 135 cities,[3] 20 maritime 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 need of using sampling methods for testing the model. The selected sample includes 30 random routes, as described in Table 2.

We estimate the travel time for each route in the sample using two methods. The first is the unrestricted optimal path, whose algorithm calculates the minimum cost between the two nodes, taking as impedance variable the travel time of each section on the network. The algorithm selects sections independently of their hierarchy. The second method uses a hierarchical algorithm.[4] 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

[3] These are the main settlements of each region of the NUTS3 classification of the appendix.
[4] To do this we use the Network Analyst utility of ArcMap 9.1.

algorithm is that it does not necessarily trace a direct route for every two nodes on the network, so the complete set of routes has to be found using an application of the minimum path problem, in this case, the Dijkstras algorithm. Despite its restrictions, the hierarchical algorithm may trace more realistic routes than an unrestricted algorithm.

The estimated travel times under the two methods are compared with the data from the SCT. The comparison shows that the unrestricted model overestimates travel times by +6 percent while the hierarchical model presents a bias 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. 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 applied to generate completely unbiased results (Table 3). The transformed travel times are the basis for the final version of the model.

The test shows that the unrestricted model is more accurate than the hierarchical model. This suggests that in this context the introduction of the hierarchical algorithm is not necessary for the estimation of more realistic routes. Finally, the test shows that the model emulates the data published by the SCT with great accuracy.

2 USA SUBSYSTEM

In this section, we present an extension to the model, which merges Mexico's GIS road network model, with a model of the USA road infrastructure, published by the Bureau of Transportation Statistics (BTS 2006) of this country. The result of this application is a complete North American GIS Road Network Model. It is based on digital cartographic information on the road network in the 48 contiguous USA sates, and Mexico.

2.1 Data for the USA Road Infrastructure

The cartographic data of the USA road network was taken from the National Transportation Atlas Database of the Bureau of Transportation Statistics (BTS 2006). The model uses all the roads in this dataset including federal, state, and local roads. The dataset does not include local roads in urban areas. Cartographic data is complete and no further modifications on the dataset were necessary.

Following Schürman and Tallat (2000), the average speed was estimated according to posted speed limits at state level. First, all roads were classified in hierarchies according to their type and number of lanes. The hierarchical classification follows the Tyger/Census Bureu Classification presented in Table 4.

Each set of roads in each hierarchy was classified in urban or rural according to the information presented in BTS (2006). Maximum posted speed limits were taken from the Insurance Institute for Highway Safety (IIIHS 2007). The Interstate Highway System (IHS) is included in the first hierarchy. Roads in the second hierarchy are defined as *other limited access roads*. Finally, roads in hierarchies three and four are classified as other roads. Urban and rural roads were allocated different average speeds. The dataset considers that a road is urban when it lies in an urban area with a population of 50,000 or more.

2.2 USA-Mexico Interconnections

Mexico and the USA are connected through 25 international border ports distributed across their common border. Twenty-one of them are fully commercial ports. The geographical location for each border port was obtained from the National Transportation Atlas Database, (BTS 2006) and validated with information from the USA Department of Transportation, published on Google Earth. The classification into commercial and non-commercial border ports follows schedules for each port published by SCT (Figure 12).

The USA and Mexico networks are not physically connected in the GIS model. An artificial line was added to the model for every border port. The length of each artificial connector was never more than nine km. Locations with more than one border port were connected only through one artificial line. Table 5 lists the 26 international ports between the two countries.

The only available data on average crossing time is available from the Texas Transportation Institute (TTI 2002). It presents estimated crossing times for three of the main USA-Mexico border ports: El Paso (POE08), Laredo (POE12), and Tijuana (POE01). The crossing time used in the model is the 95th percentile average crossing time, which is 45.2 minutes. It is worth mentioning that the Texas Transportation Institute study was carried out before the tragic events of 09/11, therefore, the delays due to modifications in security inspection might be higher today (Table 6).

The estimated crossing time between border regions in the model is equal to the estimated 95th percentile crossing delay of the Texas Transportation Institute report. However, for routes connecting non-border regions we consider an additional delay of four hours. This time considers the delay of the trailer transfer before and after crossing the border port.

3 FINAL REMARKS

We have presented a benchmark methodology for building a GIS model of the National Road Network in Mexico and linking it to the USA one by adding an artificial line for every border port. The model is useful for estimating the shortest route between any two points linked to the road system. The model estimates the average speed for every section on the network according to its hierarchy (national roads, secondary roads connecting inner cities with the main corridors or between the main corridors and their feeders, and two main ferry routes connecting the Baja California Peninsula with the main continental landmass and the

Caribbean islands of Cozumel and Isla Mujeres with the Yucatan Peninsula), regional location, toll status (tolled road or free road) and administration (federal or state).

The model can identify optimal routes by minimising travel time, although with a small bias of +6 percent in comparison to observed travel times, taken from the Mexican Ministry of Transport. This bias can be easily fixed using a linear transformation of estimated travel time, making the model useful as a stand-alone tool.

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Table 1 Average Speed by State National Road System Model

		Federal Corridor		Secondary Roads	
		Length *km*	Average Speed *km/h*	Length *km*	Average Speed *km/h*
National		**17,356.69**	**89.30**	**69,768.87**	**75.19**
S101	Aguascalientes	78.15	91.30	602.86	76.78
S102	Baja California	977.21	101.88	1,155.75	74.16
S103	Baja California Sur	952.71	77.94	568.21	75.36
S104	Campeche	634.66	90.49	1,482.12	88.89
S105	Coahuila	770.27	92.38	2,385.36	83.70
S106	Colima	118.64	94.31	509.51	82.07
S107	Chiapas	607.12	91.58	2,707.64	78.78
S108	Chihuahua	668.06	96.64	3,870.87	78.56
S109	Distrito Federal	85.07	64.83	470.63	51.94
S110	Durango	672.25	81.97	2,155.86	81.28
S111	Guanajuato	347.41	94.22	2,210.04	75.12
S112	Guerrero	212.06	113.91	2,483.88	71.61
S113	Hidalgo	155.56	95.94	1,928.97	77.20
S114	Jalisco	733.76	93.10	4,129.28	74.74
S115	México	555.47	77.59	4,105.37	68.51
S116	Michoacán	765.05	90.20	3,357.49	75.39
S117	Morelos	188.41	95.31	808.51	78.79
S118	Nayarit	252.28	94.66	967.78	76.78
S119	Nuevo Leon	833.94	85.13	3,078.50	71.45
S120	Oaxaca	682.52	64.97	2,835.32	63.87
S121	Puebla	509.16	90.67	2,746.15	65.82
S122	Querétaro	113.87	112.99	1,042.79	78.91
S123	Quintana Roo	596.76	93.56	1,162.27	90.00
S124	San Luis Potosi	685.74	82.46	1,723.10	72.85
S125	Sinaloa	751.26	94.01	1,792.75	75.36
S126	Sonora	1,159.88	102.69	4,098.18	73.42
S127	Tabasco	279.22	92.93	2,229.34	86.23
S128	Tamaulipas	858.89	87.19	2,572.87	72.95
S129	Tlaxcala	123.38	88.28	741.18	78.94
S130	Veracruz-Llave	1,373.52	93.61	4,006.44	71.33
S131	Yucatán	332.91	83.02	3,387.72	85.12
S132	Zacatecas	281.50	95.33	2,452.15	82.83

Source: Own estimates based on the Topographic Digital Dataset, INEGI (2000a)

Table 2 Accuracy Test Sample

(N=30)

Route	Distribution		Sample	
	No.	%	No.	%
City-City	9,180	56.4	19	63.3
City-Port	2,700	16.6	2	6.7
City-Border	3,375	20.7	8	26.7
Port-Port	210	1.3	0	0.0
Port-Border	500	3.1	0	0.0
Border-Border	325	2.0	1	3.3
Total	16,290	100.0	30	100.0

Source: Own calculations as explain in text

Table 3 Mean Differences between Models

	CAPUFE – U. Model		CAPUFE – H. Model	
	Absolute *h*	As % of CAPUFE	Absolute *h*	As % of CAPUFE
Mean	0.63	6%	1.16	10%
Standard Deviation	0.9	0.09	1.2	0.11
CV (Std.Dev/Mean)	1.43	1.42	1.04	1.03
Sample Size	30	30	30	30

Source: Own estimates as explain in text

Table 4 Allocation of Posted Speed Limit According to Road Type

Hierarchy	Description	IIHS Posted Speed
1	Interstate Highway System	Interstate Highway System
2	Limited Access Non-Interstate Highway System	<4 Lane Non-Interstate
3	Non Limited Access USA Highways	>4 Lane USA Highway
4	Local Roads	>4 Lane Local

Source: Own elaboration

Table 5 USA-Mexico Border Ports of Entry

	Port of Entry		State		Ports
	Mexico	US	Mex	USA	
Commercial					**Ports**
POE01	Tijuana	San Isidro/Otay	BC	CA	2
POE02	Tecate	Tecate	BC	CA	1
POE03	Sonoita	Lukerville	SON	AZ	1
POE04	Agua Prieta	Douglas	SON	AZ	1
POE05	Naco	Naco	SON	AZ	1
POE06	Heroica Nogales	Nogales Deconcini	SON	AZ	2
POE07	Puerto Palomas	Columbus	CHI	NM	1
POE08	Juarez	El Paso	CHI	TX	5
POE09	Manuel Ojinaga	Presidio	CHI	TX	1
POE10	Ciudad Acuña	Del Rio/Amistad	COA	TX	2
POE11	Piedras Negras	Eagle Pass	COA	TX	1
POE12	Nuevo Laredo	Laredo	TAMP	TX	5
POE13	Heroica Matamoros	Brownsville	TAMP	TX	4
POE14	Reynosa	Hidalgo/Pharr	TAMP	TX	2
POE15	Nuevo Progreso	Progreso	TAMP	TX	1
POE16	Ciudad Camargo	Rio Grande Cit	TAMP	TX	1
POE17	Ciudad Miguel Aleman	Roma	TAMP	TX	1
POE18	Mexicali	Calexico/Calexico East	BC	CA	2
POE19	Los Algodones	San Andrade	BC	CA	1
POE20	San Luis Rio Colorado	San Luis Rio Colorado	SON	AZ	1
POE21	Sasabe	Sasabe	SON	AZ	1
No Commercial					
POE22	Gustavo Diaz Ordaz	Los Ebanos (Ferry)	TAMP	TX	1
POE23	Guadalupe Bravo	Fabens	CHI	TX	1
POE24	Presa Falcon	Falcon Dam	TAMP	TX	1
POE25	El Berrendo	Antelope Wells	CHI	NM	1

Source: Mexico Secretary of Foreign Affairs, Mexico Secretary of Communications and Transport, and USA Department of Transport

Table 6 Estimated Delays in selected USA-Mexico Ports of Entry

Port of Entry	Type	Average Delay /1	Average Crossing Time /2	95th Percentile /3
		minutes	minutes	minutes
All	Outbound	24.9	17.2	45.2 *
	Inbound	11.6	33.8	64.9
El Paso	Outbound	29.6	13.2	34
	Inbound	4.2	37.2	77.4
Laredo	Outbound	18.9	17.2	45
	Inbound	15.4	31.2	54.9
Otay	Outbound	28.6	19.1	36.9
	Inbound	9.6	35	64.3

/1 Difference between the average crossing time and the free-flow crossing time.

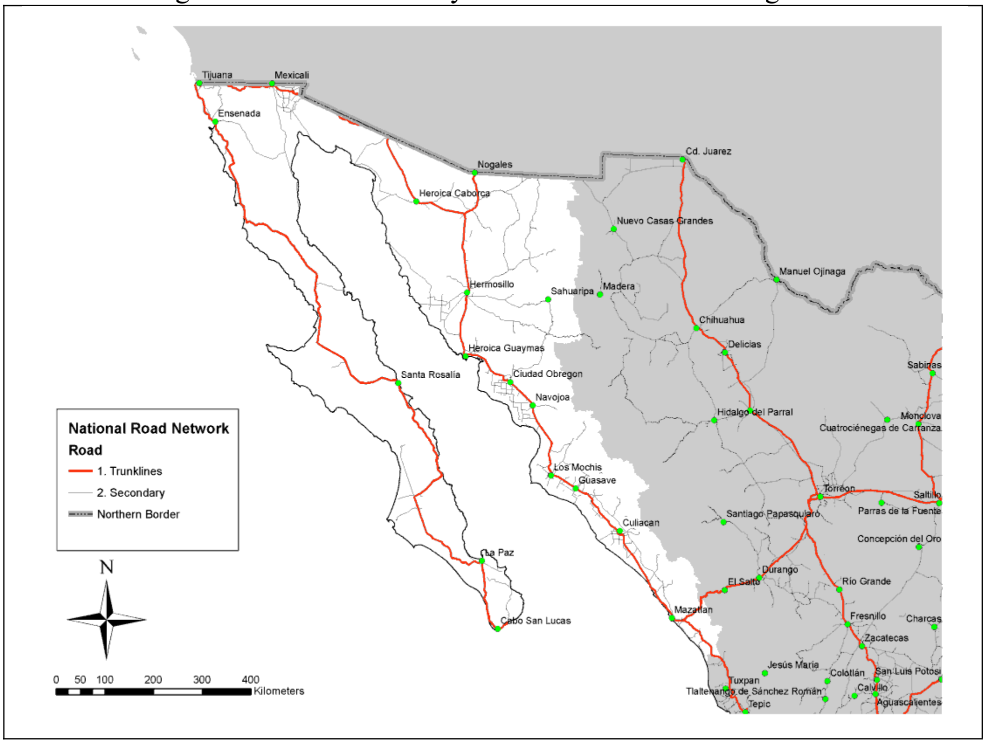
/2 Average time to travel between the starting point in the exporting country and the initial inspection point in the importing country

/2 Crossing time for the 95th percentile time for trucks to travel.

Source: International Border Crossing truck Travel Time 2001

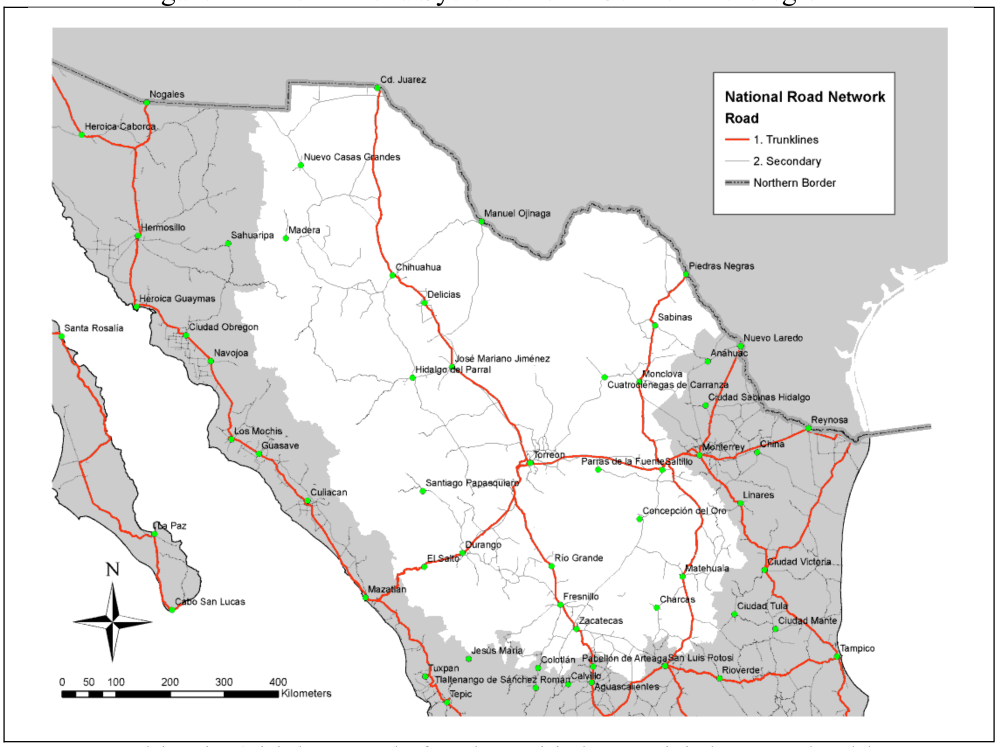
Texas Transportation Institute, Texas A&M University (2002)

Figure 1 National Road System: Northwest Macroregion I



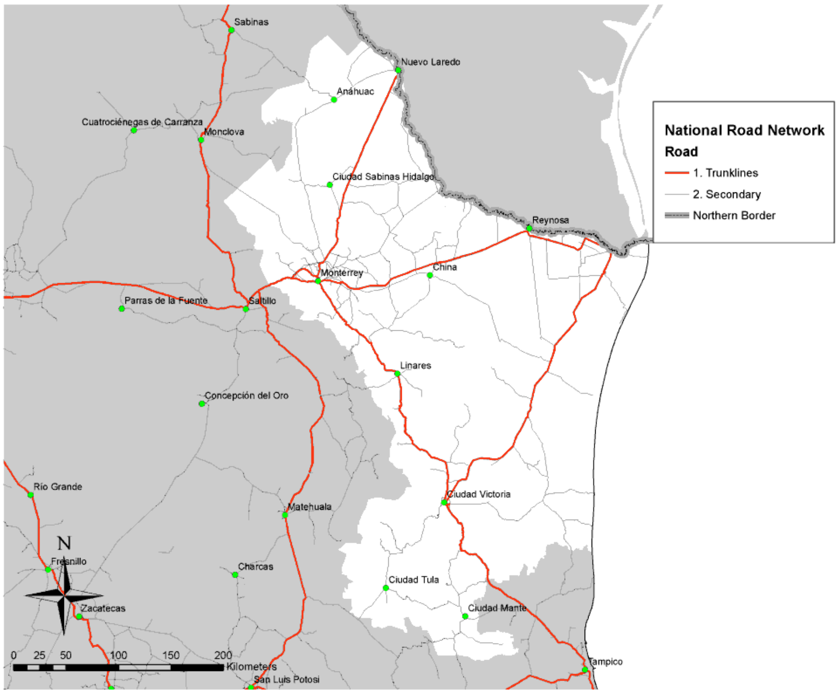
Source: Own elaboration (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset, INEGI)

Figure 2 National Road System: North Centre Macroregion II



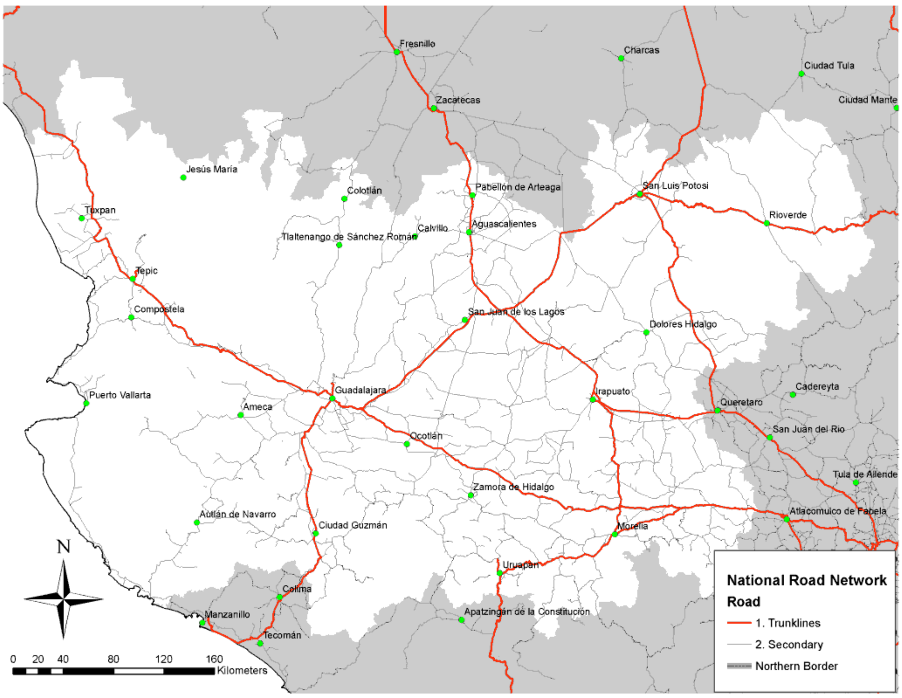
Source: Own elaboration (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset, INEGI)

Figure 3 National Road System: Northeast Macroregion III



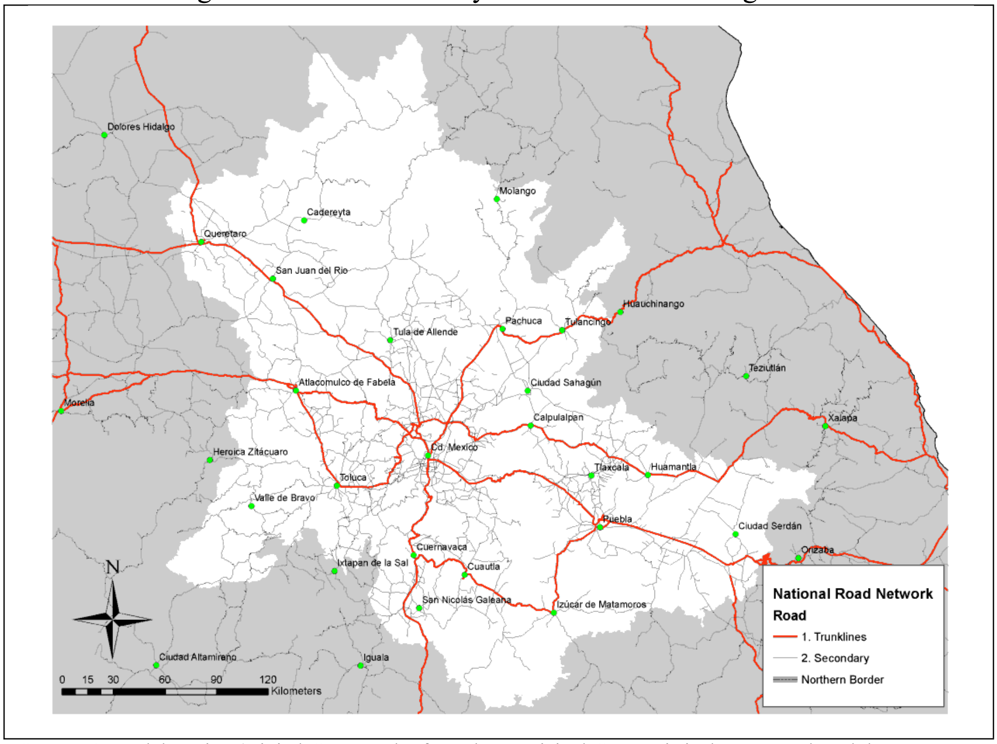
Source: Own elaboration (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset, INEGI)

Figure 4 National Road System: West Macroregion IV



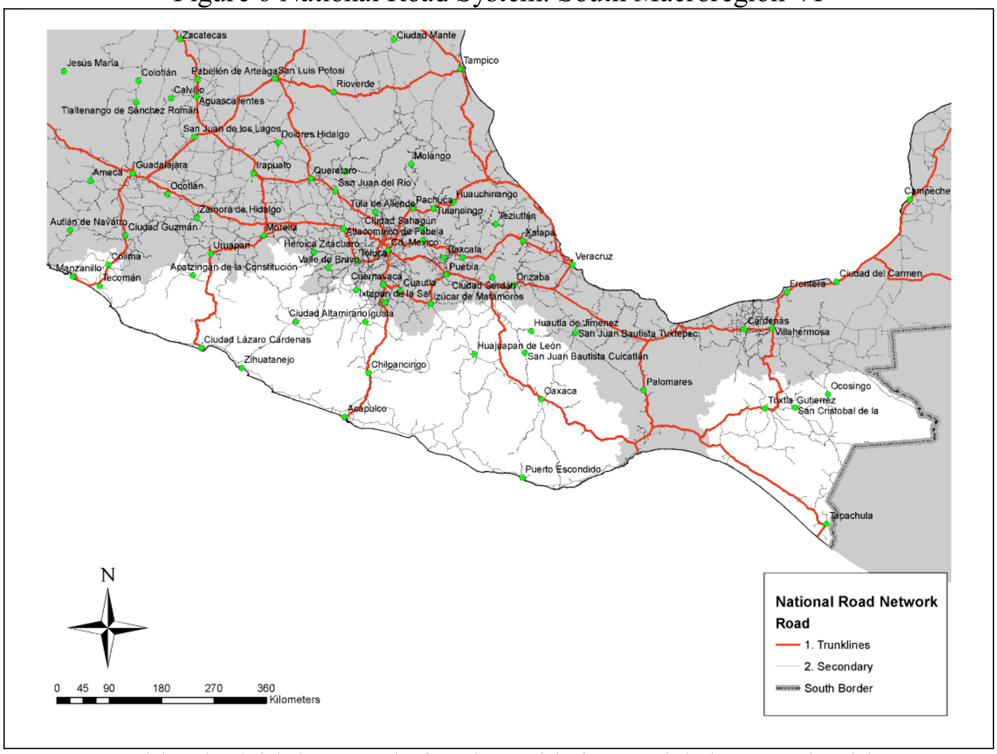
Source: Own elaboration (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset, INEGI)

Figure 5 National Road System: Centre Macroregion V



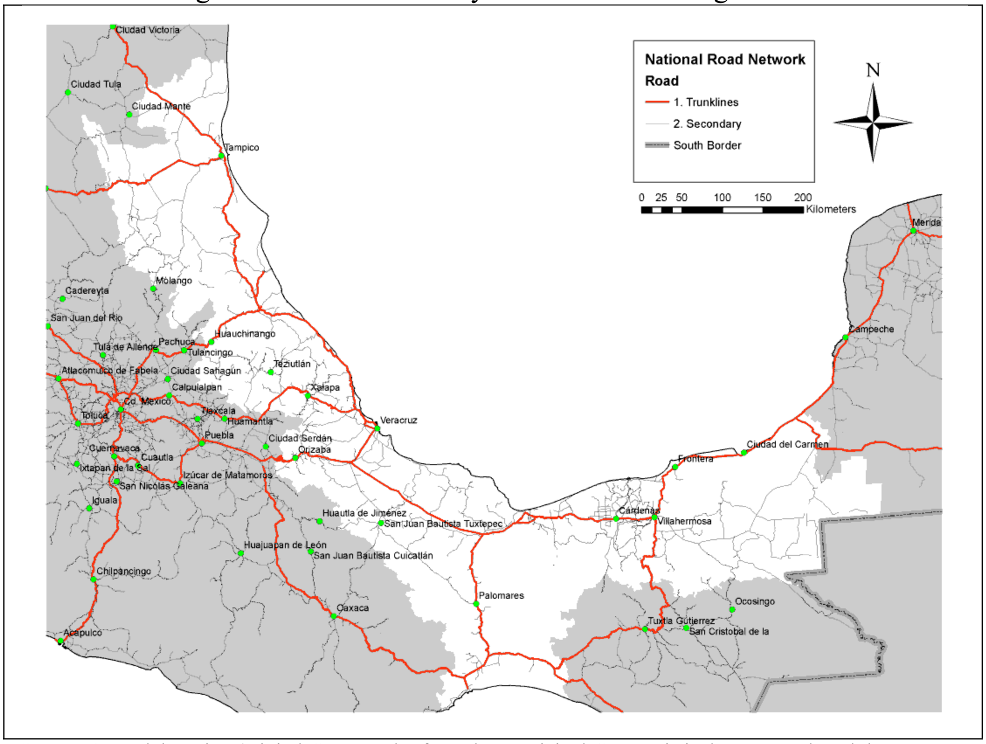
Source: Own elaboration (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset, INEGI)

Figure 6 National Road System: South Macroregion VI



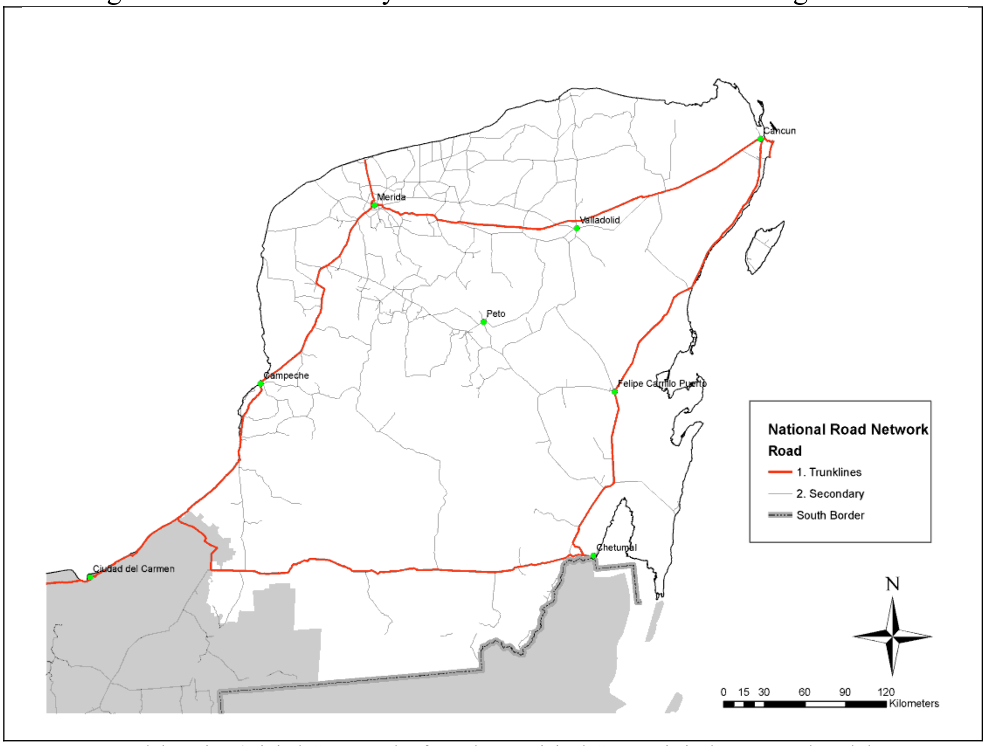
Source: Own elaboration (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset, INEGI)

Figure 7 National Road System: East Macroregion VII



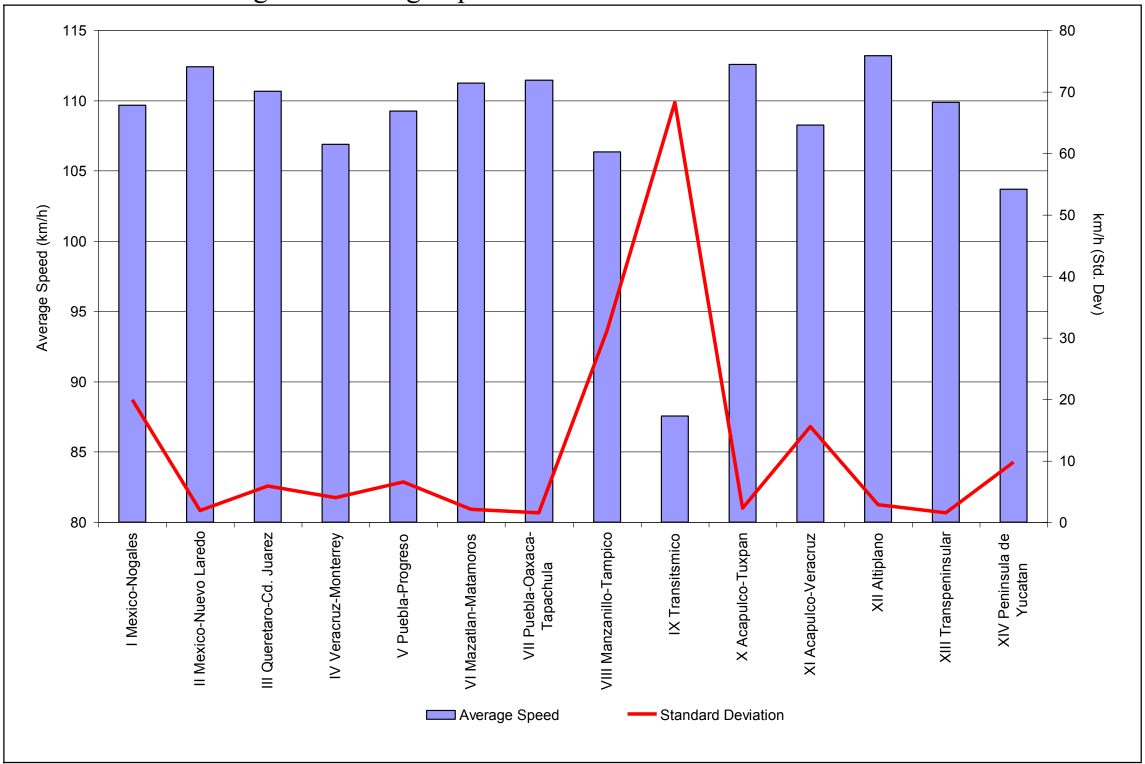
Source: Own elaboration (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset, INEGI)

Figure 8 National Road System: Yucatan Peninsula Macroregion VIII



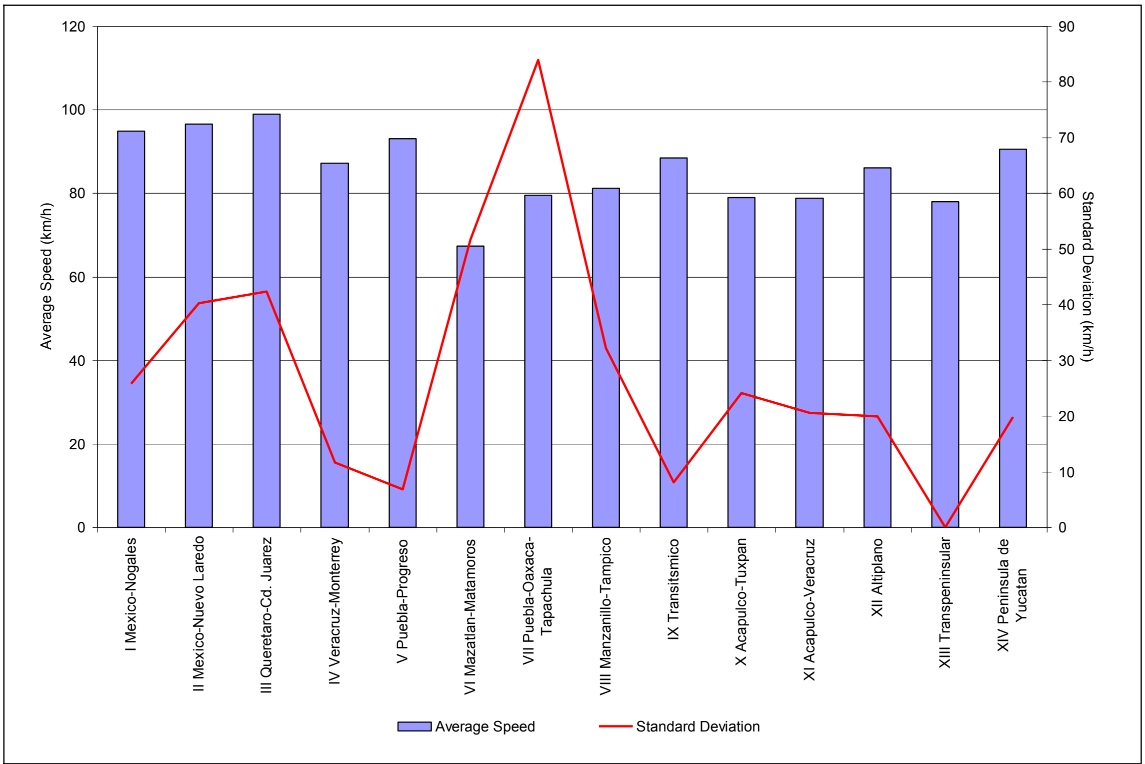
Source: Own elaboration (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset, INEGI)

Figure 9 Average Speed on National Corridors Toll Roads



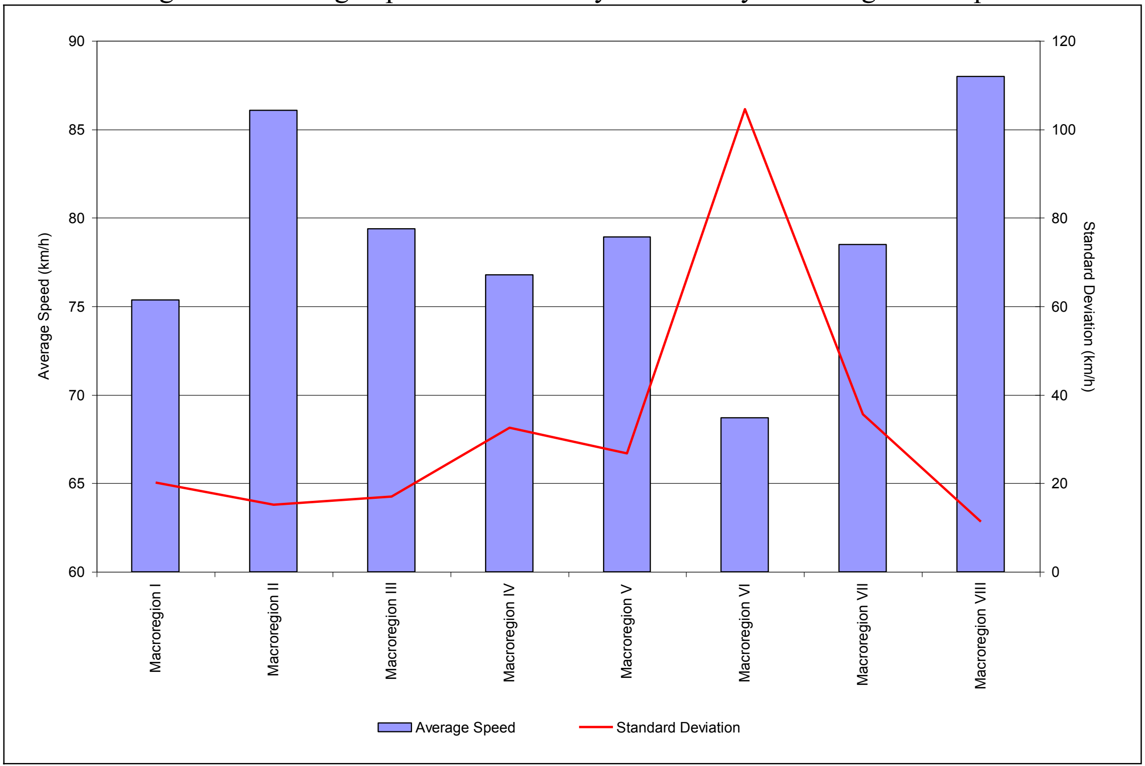
Source: Own elaboration

Figure 10 Average Speed on National Corridors.
Toll-Free



Source: Own elaboration

Figure 11. Average Speed on Secondary Network by Macroregion Sample



Source: Own elaboration

Figure 12 International Ports of Entry.

Source: Own elaboration based on the Secretary of Foreign Affairs, Secretary of Communications and Transport, and USA Department of Transport (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset, INEGI and the National Transportation Atlas Database, BTS)

APPENDIX

Table A.1 Mexico States
Nomenclature of Territorial Unit for Statistics NUTS2

Code	State	
S101	AGS	Aguascalientes
S102	BCN	Baja California
S103	BCS	Baja California Sur
S104	CAMP	Campeche
S105	COAH	Coahuila
S106	COL	Colima
S107	CHIS	Chiapas
S108	CHIH	Chihuahua
S109	DF	Distrito Federal
S110	DGO	Durango
S111	GTO	Guanajuato
S112	GRO	Guerrero
S113	HDG	Hidalgo
S114	JAL	Jalisco
S115	MEX	México
S116	MICH	Michoacán
S117	MOR	Morelos
S118	NAY	Nayarit
S119	NL	Nuevo Leon
S120	OAX	Oaxaca
S121	PUE	Puebla
S122	QRO	Querétaro
S123	QROO	Quintana Roo
S124	SLP	San Luis Potosi
S125	SIN	Sinaloa
S126	SON	Sonora
S127	TAB	Tabasco
S128	TAM	Tamaulipas
S129	TLAX	Tlaxcala
S130	VER	Veracruz-Llave
S131	YUC	Yucatán
S132	ZAC	Zacatecas

Table A.2 USA States
Nomenclature of Territorial Unit for Statistics NUTS2

Code	State		Code	State	
S201	AL	Alabama	S230	MT	Montana
S202	AK	Alaska	S231	NE	Nebraska
S204	AZ	Arizona	S232	NV	Nevada
S205	AR	Arkansas	S233	NH	New Hampshire
S206	CA	California	S234	NJ	New Jersey
S208	CO	Colorado	S235	NM	New Mexico
S209	CT	Connecticut	S236	NY	New York
S210	DE	Delaware	S237	NC	North Carolina
S211	DC	District of Columbia	S238	ND	North Dakota
S212	FL	Florida	S239	OH	Ohio
S213	GA	Georgia	S240	OK	Oklahoma
S215	HI	Hawaii	S241	OR	Oregon
S216	ID	Idaho	S242	PA	Pennsylvania
S217	IL	Illinois	S244	RI	Rhode Island
S218	IN	Indiana	S245	SC	South Carolina
S219	IA	Iowa	S246	SD	South Dakota
S220	KS	Kansas	S247	TN	Tennessee
S221	KY	Kentucky	S248	TX	Texas
S222	LA	Louisiana	S249	UT	Utah
S223	ME	Maine	S250	VT	Vermont
S224	MD	Maryland	S251	VA	Virginia
S225	MA	Massachusetts	S253	WA	Washington
S226	MI	Michigan	S254	WV	West Virginia
S227	MN	Minnesota	S255	WI	Wisconsin
S228	MS	Mississippi	S256	WY	Wyoming
S229	MO	Missouri			

Table A.3 Mexico's Regions NUTS3

Code	Region	Code	Region
R1001	Calvillo	R1040	Ciudad Sahagun y Apan
R1002	Pabellon y Tepezala	R1041	Jacala y Molango
R1003	Sur de Aguascalientes	R1042	Pachuca
R1004	Ensenada	R1043	Tulancingo
R1005	Tijuana	R1044	Valle del Mezquital y Tula
R1006	Desierto de Vizcaino y Santa Rosalia	R1045	Ameca
		R1046	Costa Sur de Jalisco y Autlan
R1007	Valle de Santo Domingo y La Paz	R1047	Guadalajara
R1008	Valle del Sur BCS	R1048	Los Altos
R1009	Campeche y Champoton	R1049	Norte de Jalisco
R1010	Ciudad del Carmen	R1050	Ocotlan y La Barca
R1011	Monclava	R1051	Puerto Vallarte
R1012	Nueva Rosita y Muzquiz	R1052	Sur de Jalisco
R1013	Parras	R1053	Noroeste de Estado de Mexico y Atlacomulco
R1014	Piedras Negras y Acuna		
R1015	Saltillo	R1054	Sur del Estado de Mexico
R1016	Sierra Mojada y Cuatro Cienagas	R1055	Toluca y Lerma
R1017	Manzanillo	R1056	Valle de Bravo
R1018	Noreste de Colima	R1057	Cienagas de Chapala y Zamora
R1019	Tecoman	R1058	Costa de Michoacan y Lazaro Cardenas
R1020	Altos de Chapas y San Cristobal de Las Casas	R1059	Meseta Purepecha y Uruapan
R1021	Centro de Chiapas y Tuxtla Gutierrez	R1060	Morelia
		R1061	Noreste de Michoacan
R1022	Comitan y Lacandonia	R1062	Valle de Apatzingan
R1023	Costa de Chiapas y Soconusco	R1063	Cuautla
R1024	Allende y Jimenez	R1064	Cuernavaca
R1025	Casas Grandes	R1065	Puente de Ixtla y Zacatepec
R1026	Parral	R1066	Centro de Nayarit y Tepic
R1027	Sierra Traumara	R1067	Norte de Nayarit
R1028	Valle de Delicias	R1068	Sierra de Nayarit
R1029	Valle de Juarez	R1069	Sur de Nayarit
R1030	Valle del Bajo Conchos y Ojinaga	R1070	Anahuac y Sabinas de Hidalgo
R1031	Valle del Centro de Chihuahua	R1071	Cerralvo
R1032	Sierra Norte de Durango	R1072	China
R1033	Sierra Sur de Durango	R1073	Linares y Montemorelos
R1034	Valle del Centro de Durango	R1074	Monterrey
R1035	Norte de Guanajuato	R1075	Costa de Oaxaca
R1036	Acapulco	R1076	La Canada
R1037	Centro de Guerrero y Chilpancingo	R1077	Papaloapan
R1038	Ixtapa y Zihuatanejo	R1078	Valle Central
R1039	Norte de Guerrero e Iguala	R1079	Izucar de Matamoros

Table A.3 Mexico Regions (continuation)

Code	Region	Code	Region
R1079	Izucar de Matamoros	R1108	Jaumave y Tula
R1080	Oriental y Ciudad Serdan	R1109	Nuevo Laredo
R1081	Puebla de los Angeles y Atlixco	R1110	Calpulalpan
R1082	Sierra Norte de Puebla	R1111	Huamantla
R1083	Teziutlan	R1112	Tlaxcala y Apizaco
R1084	Ciudad de Queretaro	R1113	Jalapa y Martinez de la Torre
R1085	Norte de Queretaro y Cadereyta	R1114	Orizaba y Cordoba
R1086	San Juan del Rio	R1115	Puerto de Veracruz
R1087	Carrillo Puerto	R1116	Peto
R1088	Chetumal	R1117	Valladolid
R1089	Charcas	R1118	Centro de Zacatecas
R1090	Rioverde y Ciudad del Maiz	R1119	Fresnillo y Sombrerete
R1091	Suroeste de San Luis	R1120	Norte de Zacatecas
R1092	Culiacan y Valle del Centro de Sinaloa	R1121	Rio Grande
		R1122	Valles de Juchipila y Tlaltenango
R1093	Guasave y Guamuchil	R1123	Cancun y Tizimin
R1094	Los Mochis	R1124	Region del Centro y Villahermosa y Norte de Chiapas
R1095	Valle de Sinaloa y Mazatlan		
R1096	Caborca y Altar	R1125	Comarca Lagunera
R1097	Ciudad Obregon	R1126	Cuenca de Mexico
R1098	Costa de Sonora y Hermosillo	R1127	Dr. Arroyo Galeana y Salado de San Luis y Matehuala
R1099	Guaymas		
R1100	Montana de Sonora	R1128	Bajio
R1101	Navojoa	R1129	Itsmo de Tehuantepec
R1102	Nogales y Cananea	R1130	La Mixteca
R1103	La Chontalpa y Cardenas	R1131	Las Huastecas
R1104	Los Rios	R1132	Valle de Mexicali, Tecate y San Luis Rio Colorado
R1105	Bravo Bajo Matamoros		
R1106	Centro de Tamaulipas y Ciudad Victoria	R1133	Papaloapan
		R1134	Region Henequenera
R1107	El Mante	R1135	Tierra Caliente

Based on INEGI (2000a, 2000c) and Bassols-Batalla (1993, 2002)

Table A.4 USA's Regions NUTS3

Code	Region	Code	Region
R2001	Aberdeen	R2041	Corpus Christi-Kingsville
R2002	Abilene	R2042	Dallas-Fort Worth
R2003	Albany	R2043	Davenport-Moline-Rock Island
R2004	Albany-Schenectady-Amsterdam	R2044	Dayton-Springfield-Greenville
R2005	Albuquerque	R2045	Denver-Aurora-Boulder
R2006	Alpena	R2046	Des Moines-Newton-Pella
R2007	Amarillo	R2047	Detroit-Warren-Flint
R2008	Anchorage	R2048	Dothan-Enterprise-Ozark
R2009	Appleton-Oshkosh-Neenah	R2049	Dover
R2010	Asheville-Brevard	R2050	Duluth
R2011	Atlanta-Sandy Springs-Gainesville	R2051	El Paso
R2012	Augusta-Richmond County	R2052	Erie
R2013	Austin-Round Rock	R2053	Eugene-Springfield
R2014	Bangor	R2054	Evansville
R2015	Baton Rouge-Pierre Part	R2055	Fargo-Wahpeton
R2016	Beaumont-Port Arthur	R2056	Farmington
R2017	Bend-Prineville	R2057	Fayetteville-Springdale-Rogers
R2018	Billings	R2058	Flagstaff
R2019	Birmingham-Hoover-Cullman	R2059	Fort Smith
R2020	Bismarck	R2060	Fort Wayne-Huntington-Auburn
R2021	Boise City-Nampa	R2061	Fresno-Madera
R2022	Boston-Worcester-Manchester	R2062	Gainesville
R2023	Buffalo-Niagara-Cattaraugus	R2063	Grand Forks
R2024	Burlington-South Burlington	R2064	Grand Rapids-Muskegon-Holland
R2025	Cape Girardeau-Jackson	R2065	Great Falls
R2026	Casper	R2066	Greensboro--Winston-Salem--High
R2027	Cedar Rapids	R2067	Greenville
R2028	Champaign-Urbana	R2068	Greenville-Spartanburg-Anderson
R2029	Charleston	R2069	Gulfport-Biloxi-Pascagoula
R2030	Charleston-North Charleston	R2070	Harrisburg-Carlisle-Lebanon
R2031	Charlotte-Gastonia-Salisbury	R2071	Harrisonburg
R2032	Chicago-Naperville-Michigan Cit	R2072	Hartford-West Hartford-Williman
R2033	Cincinnati-Middletown-Wilmington	R2073	Helena
R2034	Clarksburg	R2074	Honolulu
R2035	Cleveland-Akron-Elyria	R2075	Houston-Baytown-Huntsville
R2036	Colorado Springs	R2076	Huntsville-Decatur
R2037	Columbia	R2077	Idaho Falls-Blackfoot
R2038	Columbia-Newberry	R2078	Indianapolis-Anderson-Columbus
R2039	Columbus-Auburn-Opelika	R2079	Jacksonville
R2040	Columbus-Marion-Chillicothe	R2080	Jackson-Yazoo City

Table A.4 USA Regions (continuation)

Code	Region
R2081	Johnson City-Kingsport-Bristol
R2082	Jonesboro
R2083	Joplin
R2084	Kansas City-Overland Park-Kansa
R2085	Kearney
R2086	Kennewick-Richland-Pasco
R2087	Killeen-Temple-Fort Hood
R2088	Knoxville-Sevierville-La Follete
R2089	La Crosse
R2090	Lafayette-Acadiana
R2091	Lake Charles-Jennings
R2092	Las Vegas-Paradise-Pahrump
R2093	Lewiston
R2094	Lexington-Fayette--Frankfort--R
R2095	Lincoln
R2096	Little Rock-North Little Rock-P
R2097	Los Angeles-Long Beach-Riverside
R2098	Louisville-Elizabethtown-Scotts
R2099	Lubbock-Levelland
R2100	Macon-Warner Robins-Fort Valley
R2101	Madison-Baraboo
R2102	Marinette
R2103	Mason City
R2104	McAllen-Edinburg-Pharr
R2105	Memphis
R2106	Miami-Fort Lauderdale-Miami Bea
R2107	Midland-Odessa
R2108	Milwaukee-Racine-Waukesha
R2109	Minneapolis-St. Paul-St. Cloud
R2110	Minot
R2111	Missoula
R2112	Mobile-Daphne-Fairhope
R2113	Monroe-Bastrop
R2114	Montgomery-Alexander City
R2115	Myrtle Beach-Conway-Georgetown
R2116	Nashville-Davidson--Murfreesbor
R2117	New Orleans-Metairie-Bogalusa
R2118	New York-Newark-Bridgeport
R2119	Oklahoma City-Shawnee
R2120	Omaha-Council Bluffs-Fremont

Code	Region
R2121	Orlando-The Villages
R2122	Paducah
R2123	Panama City-Lynn Haven
R2124	Pendleton-Hermiston
R2125	Pensacola-Ferry Pass-Brent
R2126	Peoria-Canton
R2127	Philadelphia-Camden-Vineland
R2128	Phoenix-Mesa-Scottsdale
R2129	Pittsburgh-New Castle
R2130	Portland-Lewiston-South Portland
R2131	Portland-Vancouver-Beaverton
R2132	Pueblo
R2133	Raleigh-Durham-Cary
R2134	Rapid City
R2135	Redding
R2136	Reno-Sparks
R2137	Richmond
R2138	Roanoke
R2139	Rochester-Batavia-Seneca Falls
R2140	Sacramento--Arden-Arcade--Truck
R2141	Salina
R2142	Salt Lake City-Ogden-Clearfield
R2143	San Angelo
R2144	San Antonio
R2145	San Diego-Carlsbad-San Marcos
R2146	San Jose-San Francisco-Oakland
R2147	Santa Fe-Espanola
R2148	Sarasota-Bradenton-Venice
R2149	Savannah-Hinesville-Fort Stewart
R2150	Scotts Bluff
R2151	Scranton--Wilkes-Barre
R2152	Seattle-Tacoma-Olympia
R2153	Shreveport-Bossier City-Minden
R2154	Sioux City-Vermillion
R2155	Sioux Falls
R2156	South Bend-Mishawaka
R2157	Spokane
R2158	Springfield
R2159	Springfield
R2160	St. Louis-St. Charles-Farmington

Table A.4 USA Regions (continuation)

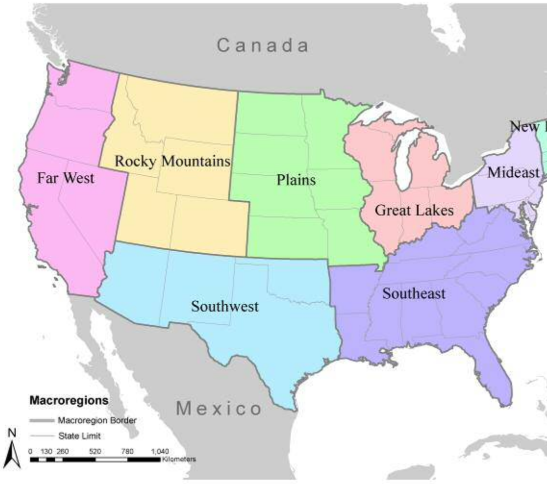
Code	Region	Code	Region
R2161	State College	R2171	Tupelo
R2162	Syracuse-Auburn	R2172	Twin Falls
R2163	Tallahassee	R2173	Virginia Beach-Norfolk-Newport
R2164	Tampa-St. Petersburg-Clearwater	R2174	Washington-Baltimore-Northern V
R2165	Texarkana	R2175	Waterloo-Cedar Falls
R2166	Toledo-Fremont	R2176	Wausau-Merrill
R2167	Topeka	R2177	Wenatchee
R2168	Traverse City	R2178	Wichita Falls
R2169	Tucson	R2179	Wichita-Winfield
R2170	Tulsa-Bartlesville		

Based on Bureau of Economic Analysis (2004a) and Bureau of Transportation Statistics (2006)

Figure A.1 Macroregions: Mexico

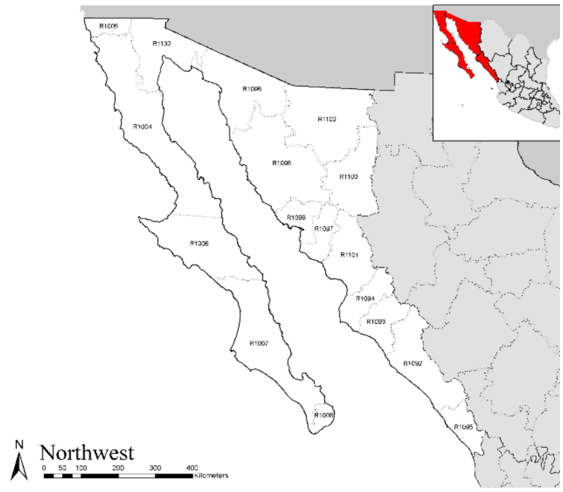
Source: Own elaboration based on Bassols-Batalla (1993, 2002) (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset)

Figure A.2 Macroregions: USA



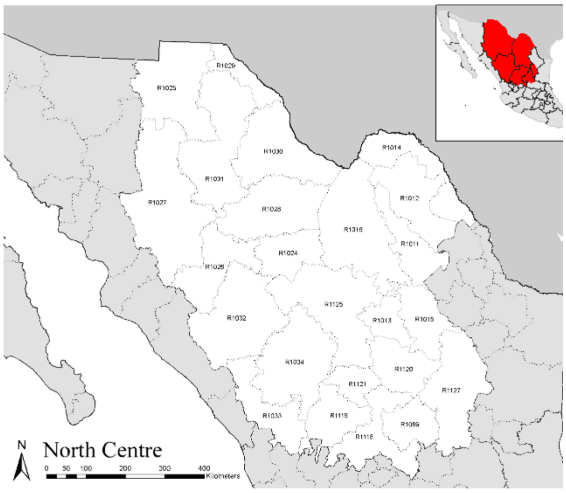
Source: Own elaboration based on the Bureau of Economic Analysis (2004b) (Digital Cartography the National Transportation Atlas Database, BTS)

Figure A.3 Regionalisation: Mexico, Northwest



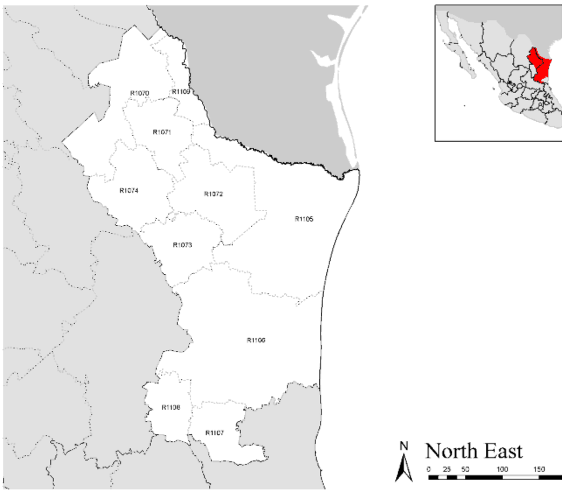
Source: Own elaboration based on Bassols-Batalla (1993, 2002) (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset)

Figure A.4 Regionalisation: Mexico, North



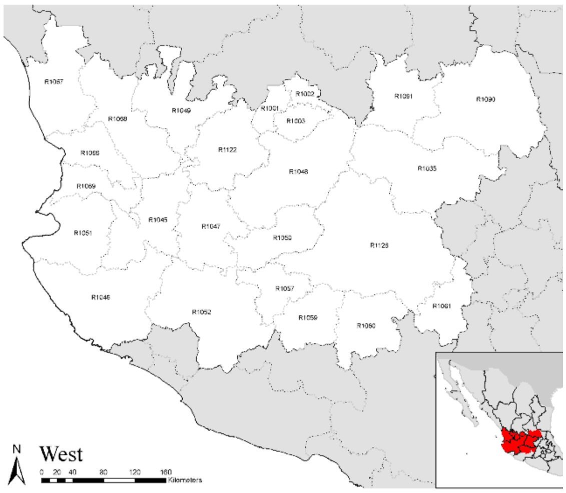
Source: Own elaboration based on Bassols-Batalla (1993, 2002) (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset)

Figure A.5 Regionalisation: Mexico, Northeast



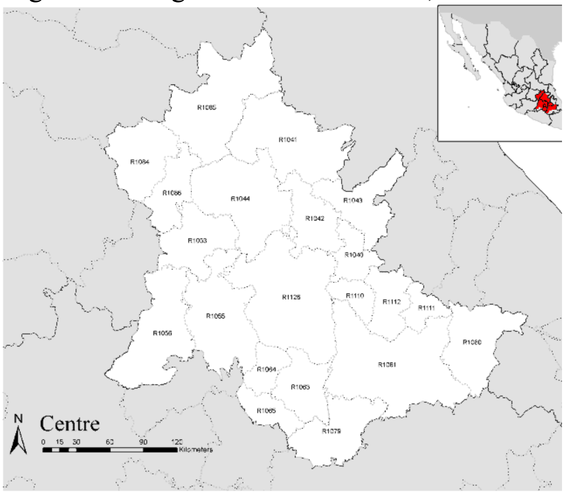
Source: Own elaboration based on Bassols-Batalla (1993, 2002) (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset)

Figure A.6 Regionalisation: Mexico, West



Source: Own elaboration based on Bassols-Batalla (1993, 2002) (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset)

Figure A.7 Regionalisation: Mexico, Centre



Source: Own elaboration based on Bassols-Batalla (1993, 2002) (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset)

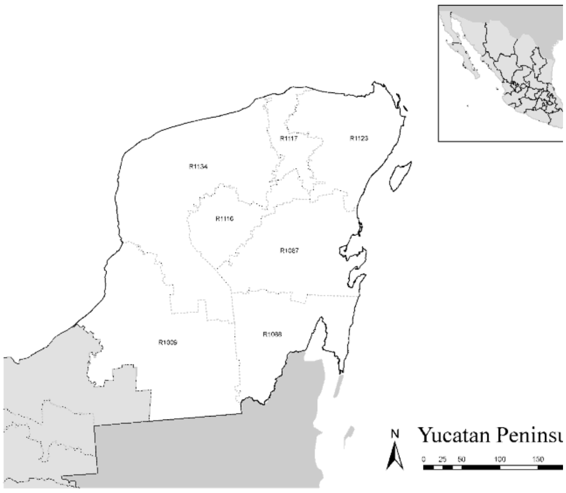
Figure A.8 Regionalisation: Mexico, South

Source: Own elaboration based on Bassols-Batalla (1993, 2002) (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset)

Figure A.9 Regionalisation: Mexico, East

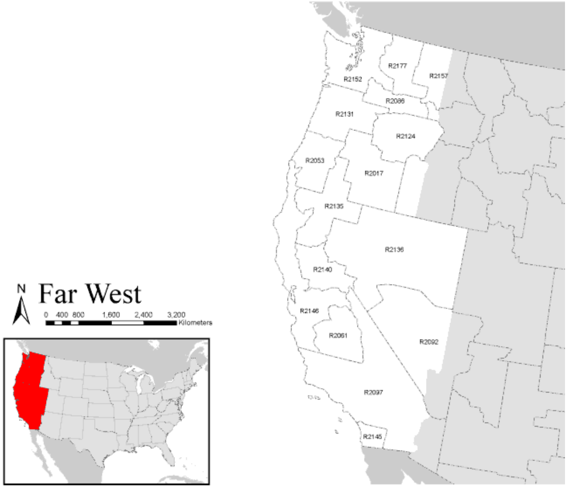
Source: Own elaboration based on Bassols-Batalla (1993, 2002) (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset)

Figure A.10 Regionalisation: Mexico, Yucatan Peninsula



Source: Own elaboration based on Bassols-Batalla (1993, 2002) (Digital Cartography from the Municipal Geo-statistical Framework and the Topographic Digital Dataset)

Figure A.11 Regionalisation: USA, Far West



Source: Own elaboration based on the Bureau of Economic Analysis (2004a) (Digital Cartography the National Transportation Atlas Database, BTS)

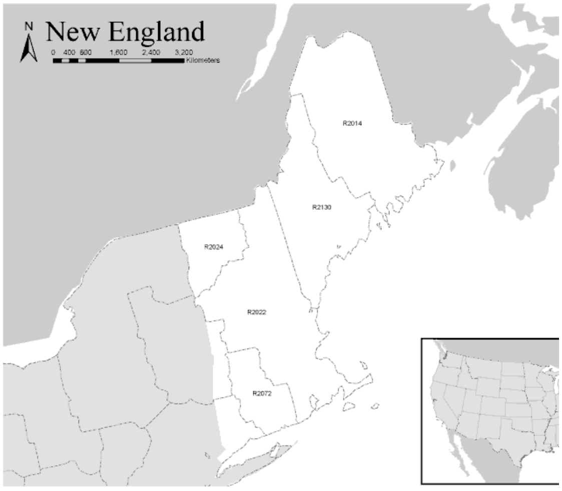
Figure A.12 Regionalisation: USA, Southwest

Source: Own elaboration based on the Bureau of Economic Analysis (2004a) (Digital Cartography the National Transportation Atlas Database, BTS)

Figure A.13 Regionalisation: USA, Southeast

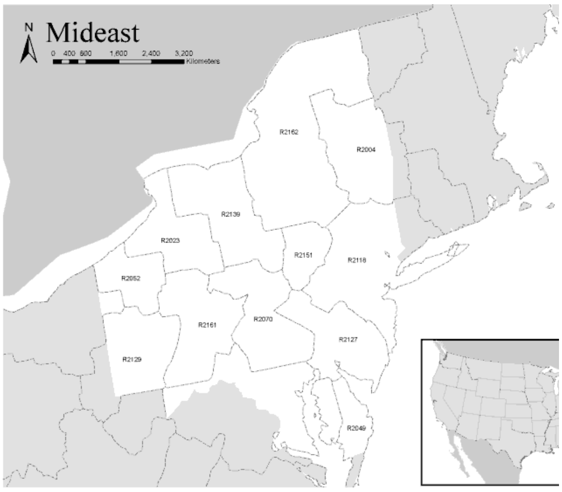
Source: Own elaboration based on the Bureau of Economic Analysis (2004a) (Digital Cartography the National Transportation Atlas Database, BTS)

Figure A.14 Regionalisation: USA, New England



Source: Own elaboration based on the Bureau of Economic Analysis (2004a) (Digital Cartography the National Transportation Atlas Database, BTS)

Figure A.15 Regionalisation: USA, Mideast

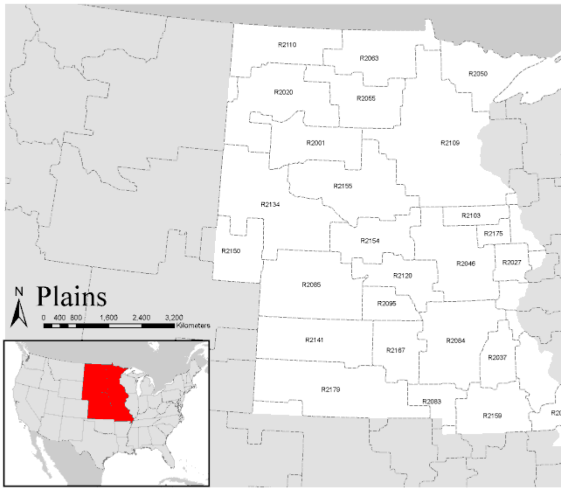


Source: Own elaboration based on the Bureau of Economic Analysis (2004a) (Digital Cartography the National Transportation Atlas Database, BTS)

Figure A.16 Regionalisation: USA, Great Lakes

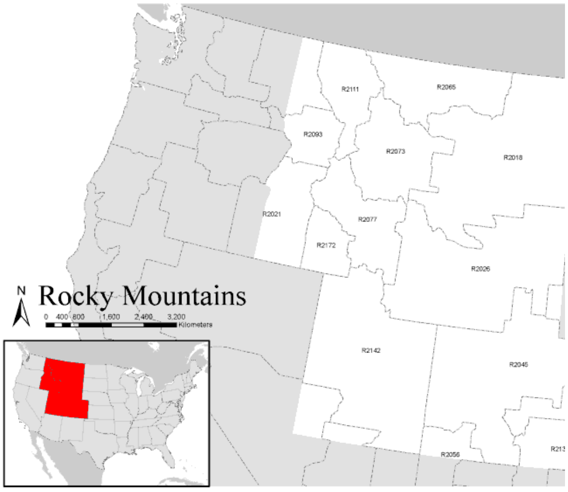
Source: Own elaboration based on the Bureau of Economic Analysis (2004a) (Digital Cartography the National Transportation Atlas Database, BTS)

Figure A.17 Regionalisation: USA, Plains



Source: Own elaboration based on the Bureau of Economic Analysis (2004a) (Digital Cartography the National Transportation Atlas Database, BTS)

Figure A.18 Regionalisation: USA, Roky Mountains



Source: Own elaboration based on the Bureau of Economic Analysis (2004a) (Digital Cartography the National Transportation Atlas Database, BTS)