OPTIMIZATION OF FREIGHT TRANSPORTATION IN SOUTHEAST MEXICO

by

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A thesis submitted to the Faculty of Graduate Studies and
Research in partial fulfillment of the requirements for the degree of

Master of Applied Science (M. A. Sc.)

Department of Civil and Environmental Engineering
Carleton University
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The Master of Applied Science program in Civil and Engineering is
a joint program with the University of Ottawa, administrated by The
Ottawa-Carleton Institute for Civil Engineering

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ISBN: 0-494-00754-0

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ISBN: 0-494-00754-0

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ABSTRACT

Important economic changes are taking place in Mexico, and new Trade Treaties with countries in Central and South America have been recently signed. This means that freight transportation in southeast Mexico will increase substantially in the coming years. Therefore, transportation infrastructure in the region has to be prepared to handle the freight flow. Research studies need to be conducted in order to assess the freight transportation situation in the region and how this situation can be improved using the current infrastructure. Research studies of freight transportation in southeast Mexico are scarce. In this thesis research, a methodological framework is defined, and using Strategic Transportation Analysis (STAN) software as a multimodal multiproduct simulator, freight transportation in southeast Mexico is investigated. Due to the complexity of this kind of analysis four products are selected and analyzed, optimization results are compared with current distribution, and conclusions are drawn regarding optimization of freight movement.

ACKNOWLEDGMENTS

First, I wish to express my sincere gratitude to my supervisor, Dr. Ata Khan for his advice and support.

In particular I wish to thank TFM because through the years that I was working there I confirmed and developed my interests in transportation. In particular I would like to thank Mr. Mario Mohar, Mr. Dan Beers and Mr. Juan Vergara for all the patience, support and guidance during the time that I was part of this interesting industry, the Railroad industry.

Many persons extended their collaboration by giving their advices and providing valuable information, data and statistics that enable me to complete important aspects of my research. I wish to recognize all these persons from the Chiapas-Mayab Railroad and from the Mexican Transportation Institute.

- Mr. Edward Palmer and Mr. Leopoldo Diaz (Chiapas-Mayab Railroad)
- Dr. Octavio Rascón, Mr. Roberto Aguerrebere, Mr. Juan C. Vázquez and Mr. Miguel A. Backhoff (Mexican Transportation Institute)

Special thanks to my wife Angelica for all her support, patience and most of all for believing in this exciting project that has brought intensity and happiness to our lives.

Last but not least, I would like to thank my parents, sisters and my new family for their continued support and prayers and to whom I will always be greatly grateful.

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GLOSSARY OF ACRONYMS AND TERMS

AADT	Annual Average Daily Traffic
ALADI	Latin American Integration Association
ALCA	Free Trade Area of the Americas
AICM	Mexico City International Airport
ASUR	Southeastern Airport Group
CANACAR	National Association of Freight Truck Transportation
CAPUFE	Federal Highways and Bridges
DOT	Department of Transportation
EU	European Union
FERROMEX	Mexican Railroad Company
FNM	Mexican National Railroad
FRA	Federal Railroad Administration
GAP	Pacific Airport Group
GATT	General Agreement on Tariffs and Trade
IMCO	Mexican Competitiveness Institute
IMT	Mexican Transportation Institute
IRI	International Roughness Index
ITE	Institute of Transportation Engineers
LOS	Level of Service
MERCOSUR	Common Market of the South
MXP	Mexican Pesos (1 MXP = 0.10 CAD)
NAFTA	North America Free Trade Agreement

OMA	North Center Airport Group
PTC	Positive Train Control
STAN	Strategic Transportation Analysis
TFM	Mexican Railroad Transportation
TM80	Montevideo Trade 1980
Ton	Metric tons
Ton/day	Metric tons per day
Ton-km	Metric ton kilometer
VOC	Vehicle Operating Costs

CHAPTER 1

RESEARCH OBJECTIVES AND METHODOLOGY

1.1 Introduction

The international economy has undergone significant changes over the past fifteen years, and it could be argued that globalization is the most important trend. In this process, economies search for greater competitive advantage and to increase their participation in world markets. Therefore, as a result of these developments, the world requires more effective, efficient and faster modes of transportation. Efficient logistics chains, including multimodal and intermodal transportation, will bring multiple benefits including a reduction in transportation costs, decreased levels of pollutant emissions into the environment, a reduction of congestion for some modes of transportation, and a more efficient use of hydrocarbons, which is an important world concern.

Transportation is an important field of human activity. In the contemporary world, transportation endorses and makes possible most commercial activities and economic exchanges. It is a complex field in which many participants are involved and where decisions and investments must be carefully planned and analyzed. Transportation is a field that requires precise and efficient tools to support and improve the analysis process, the planning procedure and the decision making phase.

Transportation plays an essential role in modern life. It is a vital part of a nation's economy, and it not only affects the availability and prices of merchandise, but also has a major impact on energy usage, national defense matters and other national concerns. Transportation system efficiency can be considered a key indicator of a country's development, and an inadequate supply of transportation service constitutes a "bottleneck" in the economy (Hay, 1961).

According to the Institute of Transportation Engineers (ITE), transportation engineering is defined as *"the scientific and technological principles applied to the planning, to the functional design, to the operation and to the facilities management of any mode of transportation, to obtain a safe, fast, comfortable, convenient, cost-effective and environmentally compatible movement of people and merchandise."*

From the definition mentioned above it can be said that transportation is the movement of people and merchandise by the different available modes. While some people would argue that the most important mode of transportation is passenger transportation, others would place more importance on freight transportation as the key factor in a society's economic operations. Nonetheless, both types of transportation should be considered an essential aspect of every country's economy (Harker, 1987).

For the transportation of people and goods it is necessary that the appropriate transportation infrastructure is provided. The transportation infrastructure in developed countries has evolved to meet both present and future requirements. In developing countries transportation infrastructure is deficient, insufficient and not well distributed throughout different regions.

Table 1.1 shows a comparison of railway and road network densities for a selection of developed and developing countries. The top countries in the table (Germany, United Kingdom, Sweden, and United States) have a greater railway and road density than the developing countries. In addition to network densities, developed countries also have other advantages including the availability and connectivity of the current transportation networks. These facilitate the provision of more efficient multimodal services at lower costs.

Table 1.1
Transportation Network Density

COUNTRY	ROADS (km/km ²)	RAILWAYS (km/1000km ²)
Germany	2	110
United Kingdom	0.6	72
Sweden	0.4	25
USA	0.67	25
South Korea	0.55	64
Pakistan	0.15	16
Mexico	0.12	13
Malaysia	0.12	5
Argentina	0.08	12
Brazil	0.16	3.5
Kenya	0.09	3.6

Source: Ministry of Communications and Transports (Mexico), 2003

The modal traffic distribution varies from country to country. Table 1.2 shows the freight traffic modal distribution of eight countries that make use of all modes of transportation. It can be observed that for Mexico, the freight traffic by modal distribution is concentrated in truck transportation.

Table 1.2
Freight Traffic by Modal Distribution (ton-km) 1992

COUNTRY	MODE				
	ROADS(%)	RAILROAD(%)	MARITIME(%)	PIPELINES(%)	AIR(%)
United States	21.2	32.1	28.6	18.8	0.3
France	47.9	33.3	4.8	14	-
Japan	46.2	3	48.3	-	0.1
Spain	74.2	7.2	16.7	1.9	-
South Korea	23.9	37.3	38.6	-	-
Malaysia	73.6	8	18.4	-	-
Brazil	52	24	20	4	-
Mexico	60	21.7	10	8	-

Source: Ministry of Communications and Transports (Mexico), 2003

Figure 1.1 shows the freight distribution in Mexico by mode of transportation for the years 1980 and 2001.

Figure 1.1: Freight Distribution by Mode of Transportation in Mexico in 1980 and 2001 (Source: Ministry of Communications and Transports, 2003)

The national road and railway network structure often restricts the availability of options for users to move their products. In Mexico, railway infrastructure is old and inefficient, while road infrastructure has experienced a great deal of growth. This has resulted in an imbalance between the two modes of transportation, and has increased the costs associated with merchandise transportation in the country.

The imbalance between road and railroad transportation in Mexico is reflected in the fact that potential railroad users still do not consider the railway as a feasible mode of transportation. They do not consider the cost and volume advantages, and they perceive the railroad as an inferior mode of transportation.

Another problem in Mexico is the lack of competitiveness between railway and truck transportation, something that has caused an inefficient cargo distribution, higher costs of transportation, and highway congestion.

Air cargo transportation in Mexico has not been considered an important mode of transportation, therefore, there are just a few facilities used for this purpose. The North Center Airport Group in Mexico has started to build new cargo facilities at some airports for different types of cargo; however, cargo services are provided in only a few Mexican airports.

For the transportation of products, many transportation operators, companies and logistics managers around the world must regularly choose between different modes of transportation, such as truck transportation, railway transportation, air transportation, and maritime transportation. However, "the transportation mode choice is still often made in a relatively irrational way" (Vannieuwenhuyse et al., 2002).

The most common criteria considered or preferred by the shippers and logistics providers for transportation mode choice are: transportation cost, reliability, flexibility, transportation time and safety. Other important criteria such as capacity, density of network, regulation and legislation, image and strategic elements, are considered less by shippers and logistics providers (Vannieuwenhuyse et al, 2002).

At present, it is common practice that shippers and carriers use logistics tools or simulators to select routes and modes of transportation for freight

transportation. Normally these routes and modes of transportation will be selected according to a specific criterion or for a specific requirement.

Advantages and disadvantages for each mode of transportation as well as for multimodal and intermodal transportation are included in Appendix A.

1.2 Problem Identification

Freight transportation problems (i.e., capacity and distribution) in some regions in Mexico have received less attention than in other parts of the country. The attention paid to these problems frequently depends on the importance of the economic activity in that region. This is the case of northern Mexico, which has experienced much economic growth over the last ten years since NAFTA was signed. In this part of Mexico, most important transportation studies and analyses have been made. In comparison, only a few studies were focused on other regions like southeast Mexico.

Important economic changes are taking place in Mexico, and new economic trade agreements with countries in Central and South America have been recently signed. This means that freight transportation in southeast Mexico will increase substantially in the following years and therefore transportation infrastructure in the region has to be prepared to handle these freight flows. At present, transportation infrastructure in southeast Mexico has started to expand and important maintenance programs and investments are scheduled for the following years.

Particularly, railroad transportation in Mexico, now controlled by the private sector, is dealing with many infrastructure and credibility problems and with a reputation as an unreliable, poor service and slow mode of transportation gained by the previous administration over the last decades. This reputation was acquired due to the lack of infrastructure investment and inefficient service offered by the State Corporation National Mexican Railroad (Ferrocarriles Nacionales de Mexico, FNM). The inefficiencies have been linked with the government agency that was controlling the service before it was privatized.

Before investing funds in the construction of new transportation infrastructure, more research studies are needed in order to know the situation of the current freight transportation in the region (type of products and volumes, freight flows, costs, distribution) and how this situation can be improved using the same infrastructure by using simulation – optimization concepts and methods.

The results of these research studies will be also useful to:

- plan ahead and prioritize the construction of transportation infrastructure,
- reduce transportation costs,
- reduce diesel fuel consumption in freight transportation and,
- reduce the pollution to the environment

1.3 Research objectives

The main objective of this thesis research is to perform an optimization of the current freight transportation in southeast Mexico considering its current transportation infrastructure and from a social point of view. Due to the complexity of this task, the optimization will be performed for only four of the main products moved in the region. In other words, the main objective is to find the best distribution of the main four products transported in the region considering its current transportation infrastructure.

Other objectives are to:

- Determine the current situation of the transportation infrastructure in southeast Mexico.
- Confirm the importance and benefits of this kind of analysis.
- Determine the transportation competition between rail and truck transportation in the region.
- Confirm the importance of the idea that all modes of transportation need to work together in order to improve the transportation process and reduce costs, congestion, travel time, diesel fuel consumption and pollution.
- Study advantages and disadvantages of using transportation simulation methodology.
- Draw conclusions and make recommendations which could help shippers, carriers, transportation planners and researchers in their decision making process.

1.4 Research Methodology

A simulation tool was selected as an aid to the optimization of the freight transportation in southeast Mexico. To facilitate this kind of analysis and optimization, various methods have been developed by researchers and incorporated in computer software.

Simulation is commonly used to describe a model that attempts to represent a current behavior and offers the opportunity to observe and evaluate in terms of cost, time and reliability of alternative solutions or the impact of major improvements or changes in the transportation infrastructure. In situations such as the present research, a field experiment or other type of experiment is impossible, therefore a simulation - optimization tool is considered more practical.

Figure 1.2 shows the components of the overall research methodology used in this study. The first step of the research framework was to identify and clearly define the problem and the objectives of this study. In the next step a decision needed to be made about the concept of simulation – optimization technique. Because various modes of transportation and products were included in the analysis, it was decided that the multimodal multiproduct simulation can better address the problem identified in this study.

Figure 1.2: Research study framework

The next step was to determine the type of simulation tool that could be used to deal with the identified problem and the objectives of this research study. Currently, there are not many simulation tools available, and it was found that STAN is a flexible simulation tool that was designed more than ten years ago and that has been successfully used in many countries around the world as an aid to research in freight transportation. The fourth step was to determine the data requirements and data collection for this research study. In the fifth phase, the selected transportation network was modelled and it was calibrated using all its characteristics that were entered interactively in STAN. The next step was to run the assignment considering the volume of current products and the current origin – destination pairs for the products selected. An analysis of the results was included where the optimization results were compared with the current situation. Finally, conclusions and recommendations were made that will help to improve the freight distribution in the region.

1.5 Thesis Document Organization

Chapter 1 includes the introduction, problem identification, research objectives, research methodology and the thesis document organization.

Chapter 2 describes the current transportation infrastructure and commercial activity in Southeast Mexico. It includes the description of some characteristics like highway level of service, highway capacity and reviews

the main products moved in the region, their volumes and their origin-destination pairs. The selection of the four products is described in this chapter as well as their current distribution.

Chapter 3 covers transportation mode choice literature and its general characteristics as well as some relevant work carried out by other researchers. It includes an overview of some of the available transportation simulation – optimization tools developed by other companies and research centres including the STAN (Strategic Transportation Analysis) developed by INRO Consultants Inc. that was selected to carry out this analysis. It explains the characteristics of the selected simulation tool as an aid to optimization, data requirements, and other information needed to run the assignment. This chapter also describes the approach used to collect data from various Institutes and Ministries in Mexico as well as from other sources such as books, papers and the internet.

Chapter 4 explains step by step the procedure to create the base network, the network calibration and to input all necessary data to run the assignment.

Chapter 5 includes the preparation of the scenario for the optimization and the analysis of results which are explained and compared with the current situation.

Finally, based on the analysis of results described in Chapter 5, conclusions and recommendations are presented in Chapter 6.

Appendix A reviews the advantages and disadvantages for each mode of transportation as well as for intermodal and multimodal transportation.

Appendix B reviews the transportation infrastructure in Mexico for all modes of transportation including highways, railways, maritime ports and airports. It includes a brief description of transportation terminals and their location.

Appendix C reviews the current situation of the economy in Mexico, including commercial trades, exports and imports between Mexico and other countries, type of products moved, and the freight distribution.

Appendix D describes the algorithm used in the Strategic Transportation Analysis (STAN) software for the multimode multiproduct assignment.

Appendix E describes the characteristics of the truck trailer selected for the optimization.

Appendix F includes the graphic description of transfers defined in the analysis.

Appendix G includes information about links capacity and cargo volume assigned to free roads and toll roads.

Appendix H includes the simulation and optimization reports generated by STAN.

CHAPTER 2

TRANSPORTATION INFRASTRUCTURE AND COMMERCIAL ACTIVITY IN SOUTHEAST MEXICO

2.1 Region Location

Prior to describing the transportation infrastructure of southeastern Mexico, it is important to identify the different regions of the country. The main regions in Mexico are: northeastern, northwestern, central, central-western and south-southeastern, and each region is formed by different states. Figure 2.1 shows the regions and the states of each region.

The region that is going to be used for this analysis is the southeastern region. The region selected for this analysis is made up of the following states: Veracruz, Oaxaca, Tabasco, Campeche, Chiapas, Yucatan and Quintana Roo (Refer to Figure 2.2). It is important to note that for this analysis only the southeastern part of Veracruz, and the east part of Oaxaca will be considered.

South-Southeastern	Center-Western	Center	Northeastern
Campeche	Aguascalientes	Distrito Federal	Chihuahua
Chiapas	Colima	Hidalgo	Durango
Guerrero	Guanajuato	México	Coahuila
Oaxaca	Jalisco	Morelos	Nuevo León
Puebla	Michoacán	Tlaxcala	Tamaulipas
Quintana Roo	Nayarit		
Tabasco	Querétaro		
Veracruz	San Luis Potosí		
Yucatán	Zacatecas		
Northwestern			
Baja California			
Baja California Sur			
Sinaloa			
Sonora			

Figure 2.1: Regions Division in Mexico

(Source: Ministry of Communications and Transports Mexico, 2002)

Figure 2.2: Southeastern states location

(Source: Created with data from the Mexican Transportation Institute, 2004)

2.2 Transportation Infrastructure in Southeast Mexico

Table 2.1 shows the main transportation characteristics for all the states in Mexico, and is organized according to region. This table facilitates comparison of the transportation infrastructure of a selected region (and its states) with other regions. The characteristics included in the table are length of highways, railways, runways and docks.

Table 2.1: Transportation characteristics in each region

Region / State	Highway Length (km)	Railway Length (km)	Runway Length (thousands m ²)	Dock Length (m)
Southern (Selected area)				
Campeche	4,769	416	211.50	7,725.00
Chiapas	21,630	557	506.94	791.00
Oaxaca (25%)	4,043	159	120.19	900.00
Quintana Roo	5,110	0	545.30	23,100.00
Tabasco	8,620	300	99.00	3,946.00
Veracruz (25%)	5,637	1,807	352.72	5,277.50
Yucatán	12,268	609	230.00	10,951.00
	62,077	3,848	2,065.65	52,690.50
South				
Guerrero	15,874	94	358.00	16,110.00
Puebla	8,737	1057	68.00	0.00
Veracruz (75%)	16,912	1355.25	264.54	15,832.50
Oaxaca (75%)	12,129	475.5	360.57	2,700.00
	53,652	2,982	1,051.11	34,642.50
Centern-western				
Aguascalientes	2,265	223	165.00	0.00
Colima	2,107	239	202.50	5,456.00
Guanajuato	11,456	1085	157.50	0.00
Jalisco	25,204	1108	441.45	12,967.00
Michoacán	13,348	1242	261.00	4,596.00
Nayarit	5,602	394	103.50	4,084.00
Querétaro	3,204	476	57.00	0.00
San Luis Potosí	11,007	1235	207.00	0.00
Zacatecas	11,259	671	165.00	0.00
	85,452	6,673	1,759.95	27,103.00
Center				
Distrito Federal (Mexico City)	150	274	348.57	0.00
Hidalgo	9,247	865	0.00	0.00
Estado de Mexico	10,001	1284	189.00	0.00
Morelos	2,027	259	124.74	0.00
Tlaxcala	2,493	352	0.00	0.00
	23,918	3034	662.31	0.00
Northeastern				
Coahuila	8,367	2218	175.95	0.00
Chihuahua	12,751	2655	432.90	0.00
Durango	13,121	1153	130.50	0.00
Nuevo León	7,217	1092	189.00	0.00
Tamaulipas	13,457	932	586.98	14,920.00
	54,913	8050	1,515.33	14,920.00
Northwestern				
Baja California	11,709	223	248.16	8,626.00
Baja California Sur	5,229	0	346.50	20,833.00
Sinaloa	16,391	1194	355.50	13,359.00
Sonora	23,287	2008	392.05	14,149.00
	56,616	3,425	1,342.21	56,967.00

Source: Ministry of Communications and Transports Mexico, 2002

According to highway length, five of the seven selected states are in the last sixteen places for Mexico, and only two are in the second and eleventh places respectively.

Variation in highway length can result from the following: different sizes of states, low commercial activity, and/or inadequately developed transportation infrastructure in the region. This is the case of Sinaloa and Campeche. Both states are almost the same size, but Sinaloa has 16 391 km of highways and Campeche has 4 769 km. This represents a difference of 11 622 km. This can be explained by the fact that Sinaloa is located in northwestern Mexico, where commercial activity and transportation infrastructure is greater than that of southeastern Mexico, including Campeche. This results from Mexico's commercial interest with North America, and the country's reduced commercial relations with Central and South America. It should be noted that this situation has been changing during the past several years, and new commercial agreements have been signed between Mexico, Central and South America. These changes have forced Mexico to make new investments in southeastern transportation infrastructure in order to facilitate this new commercial activity.

2.2.1 Highway Infrastructure

During the period 1990 - 1996 the highways in Mexico grew 4.5 percent, from 239 000 km of highways to 312 000 km. (Jimenez et al., 2001).

However, the highway infrastructure in the southeast is old and important investments need to be made in order to improve the conditions of the highway network in the region.

There are four main highway corridors in the southeastern part of Mexico. The first corridor goes from Puebla to Progreso in Yucatan, the second corridor extends from Merida to Villahermosa via Cancun and Chetumal, the third corridor goes from Coatzacoalcos to Juchitan via Tuxtla Gutierrez, and the fourth corridor extends from Puebla to Ciudad Hidalgo in Chiapas (border crossing with Guatemala). Refer to Figure 2.3.

Figure 2.3: Main highway corridors in southeast Mexico

(Source: Ministry of Communications and Transports Mexico, 2002)

The highways in Mexico are classified as follows:

1. "Troncales" (main highways) - these highways usually connect the big cities with high vehicle flows and high product movement;
2. "Alimentadoras" (secondary or feeding highways) - these highways connect small cities with medium vehicle flow and medium merchandise movement; and
3. "Rurales" (rural highways) - these highways connect small cities with low vehicle flow (Jimenez et al., 2001).

The federal government is responsible for the administration of the "Troncales" or main highways, and the state governments administer their respective "Alimentadoras" (secondary or feeding highways) and "Rurales" (rural highways) (Jimenez et al., 2001). Some other highways are managed by private companies.

Highways in Mexico can be classified as free or toll roads. Toll roads will be included in this analysis and optimization because costs associated with them influence the total cost of transportation and will affect the selection of the best cargo distribution.

The length of the toll and free "Troncales" highways (main highways) for the southeast are shown in Table 2.2 and Table 2.3 respectively. The lengths of

the “Alimentadora” (secondary highways) paved highways and the “Rural” highways are shown in Table 2.4 and Table 2.5 respectively.

Table 2.2
Toll highways length in southeast Mexico

Region / State	Toll Paved Highways (km)		
	Two lanes	Four or more lanes	Total
Southeast (Selected area)			
Campeche	0	40	40
Chiapas	204	0	204
Oaxaca	136	23	159
Quintana Roo	15	73	88
Tabasco	0	54	54
Veracruz	125	444	569
Yucatán	0	154	154

Source: created with data from Ministry of Communications and Transports Mexico, 2002

Table 2.3
Free main highways length in southeast Mexico

Region / State	Free Paved Highways (km)		
	Two lanes	Four or more lanes	Total
Southeast (Selected area)			
Campeche	1,242	17	1,259
Chiapas	2,112	72	2,184
Oaxaca	2,771	22	2,793
Quintana Roo	798	65	863
Tabasco	503	55	558
Veracruz	2,378	56	2,434
Yucatán	1,201	56	1,257

Source: created with data from Ministry of Communications and Transports Mexico, 2002

Table 2.4
Secondary paved highways length

Region / State	Paved Highways (km)		
	Two lanes	Four or more lanes	Total
Southeast (Selected area)			
Campeche	1,016	0	1,016
Chiapas	2,306	0	2,306
Oaxaca	1,348	0	1,348
Quintana Roo	972	95	1,067
Tabasco	2,626	9	2,635
Veracruz	2,802	8	2,810
Yucatán	1,658	67	1,725

Source: created with data from Ministry of Communications and Transports Mexico, 2002

Table 2.5
Rural highways length

Region / State	Highways (km)		
	Unpaved (km)	Paved (km)	Total
Southeast (Selected area)			
Campeche	795	1,047	1,842
Chiapas	16,509	17	16,526
Oaxaca	8,252	0	8,252
Quintana Roo	2,850	0	2,850
Tabasco	4,647	726	5,373
Veracruz	7,826	0	7,826
Yucatán	2,623	2,840	5,463

Source: created with data from Ministry of Communications and Transports Mexico, 2002

Most of the unpaved highways correspond to rural highways, and the greater amount of paved highways corresponds to Secondary highways. Nevertheless the southeast highway network connects all localities with a population greater than 15 000 people, which are the most important economic centers.

According to capacity and geometric characteristics, the highways in Mexico can be grouped in four different types:

1. **Type A:** These highways have geometric and structural characteristics that allow for the operation of all kinds of vehicles regardless of weight, dimension or capacity (Refer to Appendix E). These highways usually have two or four lanes (A2, A4).
2. **Type B:** These highways are known as interstate highways and operate with same restrictions pertaining to truck weight and dimensions as highways Type A. These highways usually have two or four lanes (B2, B4).
3. **Type C:** These highways are short in length. They operate locally in each state and connect with interstate highways. These highways have two lanes.
4. **Type D:** This classification corresponds to the "Alimentadora" highways explained before. These highways have two lanes and are short in length. They connect small localities with other main highways (Ministry of Communications and Transports Mexico, 2002).

According to the classification mentioned above, 24 percent of the total highway infrastructure in the southeast is type A, and 38 percent is type B.

The remaining 38 percent of highways is either type C or D (Jimenez et al., 2001). This distribution restricts the operation of high capacity and heavy trucks on these highways, increasing the transportation costs and impacting the economy in the region.

It is important to mention that only some of the main and secondary highway routes type A, B and C are going to be considered for this analysis.

Highway routes considered in this analysis are shown in Figure 2.4

Figure 2.4: Highway infrastructure in southeast Mexico
 (Source: Created in ArcView with data from the Mexican Transportation Institute)

Highway Capacity, Level of Service and Annual Average Daily Traffic (AADT)

Level of service and capacity for highways in southeast Mexico were determined through a study made by the Ministry of Communications and Transports and the Mexican Transportation Institute. The results of this study for highways in southeast Mexico are shown in Figure 2.5 according to the level of service. (Six levels of service were considered according to the U. S. Highway Capacity Manual).

It can be shown that most of the highway network in the southeast has a level of service between A and C, and only a few routes have a level of service D or E.

The annual average daily traffic was obtained from a study made by the Ministry of Communications and Transports for all highways in Mexico in 2001. Part of the results of this study were used and published in another study made by Jimenez et al., (2001).

The results of this study show that the average AADT in highways of southeast Mexico equals to 1928 vehicles. Eighty percent of these vehicles are represented by cars; 5 percent are represented by buses and 15 percent are represented by freight trucks.

Figure 2.5: Level of Service of the highway network in Southeast Mexico

(Source: Perez et al., 2001, Mexico)

2.2.2 Air Infrastructure

Airports in the southeast are well distributed and strategically located in the main cities of each state or in the main tourism centers (Jimenez et al., 2001). Figure 2.6 shows the location of the main airports in the southeast.

The most important airports in the southeast are administrated by Aeropuertos del Sureste (ASUR - a private company). The other minor airports in the region are administrated by Airports and Auxiliary Services (ASA - a government organization). Table 2.6 shows the distribution of airports in the southeast and their respective administration.

Figure 2.6: Airport distribution in Southeast Mexico

(Source: Mexican Transportation Institute, 2003)

Table 2.6
Airports distribution in southeast Mexico

State	ASUR		ASA		Total	
	Domestic	International	Domestic	International	Domestic	International
Campeche	-	-	-	Campeche	-	2
	-	-	-	Cd. del Carmen		
Chiapas	-	Tapachula	Comitán	Palenque	4	2
	-	-	San Cristóbal	-		
	-	-	Terán	-		
	-	-	Tuxtla Gtz.	-		
Oaxaca	-	Oaxaca	Ixtapalapa	Puerto Escondido	2	3
	-	Huatulco	Loma Bonita	-		
Quintana Roo	-	Cancun	-	Chetumal	-	3
	-	Cozumel	-	-		
Tabasco	-	Villahermosa	-	-	-	1
Veracruz	Minatitlán	Veracruz	Poza Rica	-	2	1
Yucatán	-	Merida	-	-	-	1
TOTAL	1	8	7	5	8	13

Source: Mexican Transportation Institute, 2003

According to a study carried out by the Mexican Transportation Institute, the airport of Merida is considered a hub for air cargo transportation. This airport receives domestic and international products from Caribbean, Central America, and South America, which are later transported to Miami.

Airports located in the southeast represent 33 percent of the total airport infrastructure in the country. According to the Mexican Transportation Institute, there is adequate air infrastructure coverage in the region, and an appropriate level of air communication with the rest of the country and the world.

2.2.3 Railroad Infrastructure

The total railway network in Mexico is equal to 26 623 km, and only 12.5 percent was built between 1950 and 1996. According to the Ministry of Communications and Transports (Mexico), these numbers represent an annual growth rate of 0.29 percent. During the initial years of the 1990's the railway network in Mexico grew less than one percent (262 km), and in the southeast there was an overall reduction of 0.6 percent (15km) and a growth of 14.4 km for private use railways (Jimenez et al., 2001).

The railway length in the southeast accounts for 11 percent of the total railway length in the country. The main railways in the southeast represent 12 percent of the total in the country, the secondary railways represent 7.5 percent, and the private use railways represent 8 percent (Jimenez et al.,

2001). Notice that there is no railway infrastructure in Quintana Roo and tourism is the main economic activity in this state.

The following table shows some indicators of the railway infrastructure according to population and area in Mexico and in the southeast.

Table 2.7
Statistics of Railway infrastructure in Mexico

Region	Population (POP) (97)	Area (A) (km ²)	Total Network (TN) (km)	Main Network (MN) (km)	M N/TN	TN/A (m/km ²)	TN/POP (m/person)
Mexico	93716332	1967183	26623	20687	0.77	13	0.28
Southeast	14794023	399229	2967	2496	0.84	7.4	0.2

Source: Created with data from the Mexican Transportation Institute

It can be observed that according to the railway length/area ratio, the southeast has 7.4 m/km² of railway which is less than the national average. However the railway network in the southeast has supported the economy in the region connecting the petroleum zone of Tabasco and the cement industry with the central part of the country. Nevertheless important improvements need to be done to connect Oaxaca with the port of Salina Cruz and to increase the rail capacity of the routes Coatzacoalcos - Merida and the Istmo - Guatemala.

It is important to mention that the railroad service in the region selected for the analysis (southeast) is operated by the Chiapas - Mayab Railroad. "The Chiapas - Mayab Railroad is a subsidiary of Genesee Wyoming Inc. and connects important population and transportation centers of Merida, Campeche and Coatzacoalcos along the coast of the Gulf of Mexico with

Ixtepec, Tapachula and Ciudad Hidalgo at the border with Guatemala along the Pacific Coast. The Chiapas – Mayab Railroad operates on 1,805 km of main and secondary railways and on 321 km (200 miles) of track rights between Coatzacoalcos and Salina Cruz, which allows them to connect traffic between the two routes” (Genesee Wyoming, 2004). (Refer to Figure 2.7)

Track problems in north Guatemala force the Chiapas - Mayab Railroad to connect with Central America in the south cross border with Guatemala in Ciudad Hidalgo, Mexico. This track restriction has brought many logistics problems increasing transportations costs and border crossing time (Jimenez et al., 2001).

Figure 2.7: The Chiapas - Mayab Railroad routes

(Source: Genesee Wyoming, 2004)

The railway extension and distribution in current use in southeast Mexico is shown in Table 2.8, and name of terminals and location are shown in Figure 2.7. It is important to mention that railroad terminals are equipped to manage break bulk products, liquids as well as other products. There are only two intermodal terminals in the Chiapas - Mayab network: Merida Intermodal Terminal located in Merida, Yucatan near the Port of Progreso, and Tapachula Intermodal Terminal, located in Tapachula, Chiapas near the border with Guatemala. Both intermodal terminals have all the necessary equipment for the movement of containers and for the movement of automobiles.

Table 2.8
Railway extension in use in southeast Mexico

State	Main railways (km)	Secondary railways (km)	Private use railways (km)	Total (km)
Campeche	358.00	32.90	23.80	414.70
Chiapas	471.72	51.80	15.80	539.32
Oaxaca	130.25	92.10	21.40	243.75
Quintana Roo	0.00	0.00	0.00	0.00
Tabasco	264.87	29.50	14.20	308.57
Veracruz	35.00	87.03	36.60	158.63
Yucatán	290.00	40.90	24.40	355.30
Coatzacoalcos - Salina Cruz	Not operated by the Chiapas - Mayab Railroad (321 km)			
Total (km)	1,549.84	334.23	136.20	2,020.27

Source: Created with data from the Mexican Transportation Institute and from the Chiapas Mayab Railroad

2.2.4 Maritime Infrastructure

There are 172 ports in Mexico according to the General Coordination of Ports and Merchant Marine. Fifty one ports are located in the southeast and according to their activities they are distributed in the following form: 14

commercial ports, 22 fishing ports, 11 tourism ports and 4 petroleum ports.

(Refer to Figure 2.8)

Figure 2.8: Maritime ports distribution in Southeast Mexico

(Source: Ministry of Communications and Transports Mexico, 2003)

There is at least one commercial and one fishing port in each state in the southeastern region. Nevertheless, it is evident that the port infrastructure is better equipped for fishing and tourism activities than for commercial activities.

Most important problems for ports located in southeastern Mexico are the warehouse service. Their current storage capacity represents only 10 percent of the total storage capacity in Mexico (Jimenez et al., 2001). This storage

limitation reduces commercial activities in ports and could be affecting the optimum logistics chains for certain products. It can be concluded that fishing and tourism are the main activities in southeastern ports.

Only commercial ports with a current commercial activity will be considered in this thesis for the selection of products and for the analysis. This means that only fifteen ports could be considered in the analysis.

The port of Salina Cruz is well known for its petroleum activity. It is equipped with a dock length of 971 m, a container terminal with a length of 275m, a container yard with an area of 90 000 m² and with a container crane. (Refer to Figure 2.9)

Figure 2.9: The port of Salina Cruz
(Source: The Port of Salina Cruz, 2004)

The port of Coatzacoalcos is one of the most important ports in the southeastern region. Its infrastructure includes equipment to load and unload chemicals, cement, grains, containers and general cargo. This port has an extension of 23 km of rail tracks and a storage capacity of 430 railroad cars (The Port of Coatzacolacos, 2004). (Refer to Figure 2.10)

Figure 2.10: Port of Coatzacoalcos

(Source: The port of Coatzacoalcos, 2004)

The port of Puerto Progreso is the most important commercial port in the state of Yucatan, and it has the proper infrastructure for the movement of containers, hydrocarbons and grains (Jimenez et al., 2001). (Refer to Figure 2.11)

Figure 2.11: The Port of Puerto Progreso
 (Source: The Port of Puerto Progreso, 2004)

Besides the great number of ports located in the region, only some of them have the proper infrastructure to handle international commercial flows (large amount of products and big vessels) and only four ports have the appropriate infrastructure to provide a container service (intermodal service) (Coatzacoalcos, Puerto Progreso, Salina Cruz and Puerto Morelos) (Jimenez et al., 2001).

2.2.5 Observations on Transportation Infrastructure

The highway network in the southeast connects all localities with a population of more than 15 000 people that are the main cities in the region. Ninety-five percent of the total paved roads correspond to two lane highways and in some parts these highways have capricious alignments with high grade values and important radius variation for horizontal curves (Jimenez et al., 2001). These characteristics are typical of an inconsistent highway design and usually generate important problems for the transportation of products such as: high insecurity level, congestion, low operational speed, and great times of haulage increasing considerably the costs of transportation.

Some important localities are not connected by railroad and this is the example Tuxtla Gutierrez with Tapachula and the whole state of Quintana Roo. The railroad network in the region is limited and there are some areas that are not even partially covered, affecting other possible and more efficient logistics chains for the movement of products.

Maritime ports are not commonly used for domestic commerce; in fact they are almost only used for international commerce and the movement (imports and exports) of other products from and to Asia and Europe (Jimenez et al., 2001).

Finally, according to the Mexican Transportation Institute there is a partial disintegration between modes of transportation in southeastern Mexico, and particularly between railroad and maritime ports. Definitely, this situation affects another possible product distribution from and to maritime ports, forcing the usage of truck transportation to complete the movement of certain products to maritime ports, increasing the total transportation costs.

General information about the transportation infrastructure and its evolution in all Mexico can be found in Appendix B. This Appendix includes some facts and characteristics of each mode of transportation and some aspects about the privatization process that helped to improve the freight transportation in Mexico. The information contained in this Appendix is useful to better understand the transportation infrastructure situation in all regions in Mexico.

2.3 Commercial activity in the region

Commercial activities in southeast Mexico are distributed by state and by type of activity. Fishing activity is mainly developed by the states of Chiapas,

Oaxaca and Campeche, cattle activities are mainly developed in Oaxaca and Tabasco, agriculture is developed in Oaxaca, Chiapas and Tabasco and petrochemical activities are developed in Tabasco and Campeche. The state of Quintana Roo is better known for tourism activities (Jimenez et al., 2001). (Refer to Table 2.9)

Table 2.9
Economic activities distribution in Southeast Mexico

Activity	State					
	Campeche	Chiapas	Oaxaca	Q. Roo.	Tabasco	Yucatan
Fishing		X	X			
Agriculture		X				
Cattle		X	X		X	
Petroleum	X				X	
Tourism				X		
Manufacture						X

Source: created with data from Jimenez et al. 2001, Mexico

In the following section main products moved by rail and road transportation in southeast Mexico and main origin-destination pairs will be identified.

2.4 Main products moved by road transportation

Mineral products like lime, gypsum, stones and cement are the most important products moved in southeast Mexico. Cement is the most important product produced and transported in the region with a strategic location of their facilities taking advantage of the modes of transportation serving in the region (Jimenez et al., 2001).

Southeast Mexico has always been known as an important agricultural region, therefore, cereals, grains, fruits and seeds are also important

products that are transported in the region. Other important products moved in the region are mineral fuel, mineral grease, beverages, alcoholic beverages and tobacco (Jimenez et al., 2001).

Main Origin – Destination pairs

Agricultural and agro industrial products are typical in the region and are necessary for the beer, soda and milk industry.

Transportation of cement and lime is very important in the corridor Coatzacoalcos – Salina Cruz in southeast Mexico, and motor carriers are looking for new trucks and new services to be able to transport in a more efficient way these products (Jimenez et al., 2001). The new truck services will help to improve the transportation of other specialized and break bulk products in the region like silica sand, beer and beverages.

Main origin-destination pairs are shown in Table 2.10 and Figure 2.12

Table 2.10
Main origin-destination pairs for road transportation in southeast Mexico

Origin	State	Destination	State
Merida	Yuc.	Progreso	Yuc.
Progreso	Yuc.	Merida	Yuc.
Merida	Yuc.	Cancun	Q.R.
Cancun	Yuc.	Merida	Yuc.
Teya	Yuc.	Merida	Yuc.
Chetumal	Q.R.	Merida	Yuc.
Merida	Yuc.	Chetumal	Q.R.
Merida	Yuc.	Valladolid	Yuc.
Mexico	DF	Merida	Yuc.
Mexico	DF	Tuxtla Gutierrez	Chps.
Valladolid	Yuc.	Merida	Yuc.
Tapachula	Chps.	Mexico	DF

Source: created with data from the Mexican Transportation Institute

Figure 2.12: Location of origins and destinations for road transportation
 (Source: created in ArcView with data from the Mexican Transportation Institute)

2.5 Main products moved by railroads

Products moved in the southeast are commonly unprocessed or semi processed products. Raw products include corn, silica sand, sugar cane and paper waste; semi processed products include cement, combustoleo,

minerals, wood, sugar and fertilizers. Some other products moved in the southeast include beer, paper and glass bottles (Jimenez et al., 2001).

It can be observed that most of the products moved by railroad in the southeast are break-bulk products (non-containerized conventional cargo). These products can be easily moved by railroad at lower costs; therefore, this characteristic is sometime considered a strength for railroad mode of transportation.

According to the Chiapas-Mayab Railroad, the main products transported by railroad in southeast Mexico are:

- Cement (Portland)
- Combustoleo
- Diesel and gasoline
- Wood
- Cereals
- Grains
- Silica Sand

It is important to mention that forty-two percent of the total cargo moved in southeast Mexico involves the international market and 58 percent involves the domestic market (Jimenez et al., 2001).

Main Origin – Destination pairs

Table 2.11 shows the main origin-destination pairs for products transported by railroad in southeast Mexico. It can be observed that the railroad is connecting production zones with demand zones located not only in the region but connecting with other modes of transportation to move the products to northern Mexico or to other countries. Figure 2.13 shows the location of some of these origins and destinations.

Table 2.11
Main origin-destination pairs for rail transportation in southeast Mexico

Origin	State	Destination	State	Length (km)	Product
Tepeaca	Puebla	Cd. Hidalgo	Chiapas	617	Cement
Tepeaca	Puebla	Ing.R.Ayala	Tabasco	128	Cement
Pino Suarez	Tabasco	Uman	Yucatan	605	Cement
Paraiso	Tabasco	Uman	Yucatan	389	Silic Sand
Coatzacoalcos	Veracruz	Merida	Yucatan	888	Combustoleo
Coatzacoalcos	Veracruz	Valladolid	Yucatan	1047	Combustoleo
Salina Cruz	Oaxaca	Tapachula	Chiapas	466	Diesel and gasoline
Mosquitero	Tabasco	Morelia	Michoacan	107	Wood
Mosquitero	Tabasco	Maravatio	Michoacan	107	Wood
Sinaloa	Sinaloa	Merida	Yucatan	895	Grains
Veracruz	Veracruz	Arriaga	Chiapas	311	Cereals
Tlalnepantla	Edo. Mexico	Cd. Hidalgo	Chiapas	617	Major appliances

Source: created with data from the Chiapas-Mayab Railroad

Figure 2.13: Location of origins and destinations for rail transportation
 (Source: created in ArcView with data from the Mexican Institute of Transportation)

It can also be observed that railroad connects cities that most of the times are not the capitals or the main cities in the region like the case of the route Tepeaca – Cd. Hidalgo. Railroad exports are clearly observed connecting the country and southeast Mexico with Central America (Guatemala) in Cd. Hidalgo, Chiapas. This is the case of cement moved from Tepeaca, Ver. to Cd. Hidalgo, or major appliances moved from Tlanepantla (located near Mexico City) to Cd. Hidalgo.

2.6 Main products moved by maritime ports

Products moved to and from maritime ports were considered for this analysis. Main connections of maritime ports in southeast Mexico with other regions in the world are described in Figure 2.14.

Figure 2.14: Freight flows between maritime ports in southeast Mexico and other ports in the world. (Source: Jimenez et al., 2001)

In 1998 maritime ports in the southeast transported 17 millions of tons with the following distribution: 92 percent of petroleum and its derivatives and 8 percent of general cargo (Jimenez et al., 2001).

The ports of Salina Cruz and Progreso are the ports that have a closer relationship with other ports in the country, in fact, the 80 percent of the

total products moved between southeast ports and other ports in the country are handled by these two ports (Jimenez et al., 2001).

Ninety seven percent of the total products moved by ports located in the pacific coast are petroleum and its derivatives and three percent is general cargo. For products moved by ports located in the Gulf of Mexico the situation is a little different, 68 percent corresponds to petroleum and its derivatives and 32 percent correspond to general cargo (Ministry of Communications and Transports, 2004).

Other products moved in the southeast are: cement, sugar, beer, chemical products, soy, corn, sorghum, wheat, coffee beans, and soft drinks (Jimenez et al., 2001).

2.7 Containers movement

Maritime ports in the region don't have the proper infrastructure and facilities to move containers; therefore, container movement in the region is limited (Jimenez et al., 2001).

The only ports in the region that are currently moving containers are: the port of Progreso in Yucatan and the port of Puerto Morelos in Quintana Roo. These ports moved 60 369 TEUS, and 7 515 TEUS respectively in 2003, and the total moved by these two ports represents the 4.03 percent (67 884

TEUS) of the total TEUS moved in all ports in Mexico (1 683 400 TEUS) (Ministry of Communications and Transports Mexico, 2004).

The Chiapas-Mayab railroad reported a movement of 260 TEUS in the year 2003 and expectations are to increase this traffic in the following years (Chiapas-Mayab Railroad, 2004).

2.8 Products selected for the optimization

Based on all information about the commercial activity in southeast Mexico covered in this chapter, the following four products are selected for the optimization:

- Cement (Portland)
- Combustoleo (Fuel)
- Corn
- Wood

These four products were also selected according to the following criteria:

- they are the most important products moved in the region according to their volumes,

- these four products represent 23 percent of the total products moved in the region (609 270 t/week); 9 percent of this total is moved by railroad and 91 percent is moved by road transportation,
- these four products represent almost 50 percent of the total freight moved by the Chiapas-Mayab Railroad (55 000 tons/week) with an average volume of 26 757 tons/week,
- road transportation moves an average of 554 277 t/wk, and 20 percent of this total freight (114 853 t/wk) is represented by the four products selected for the analysis.

The following are some other important characteristics for the products selected for the optimization:

- the four products can be transported by railroad and roads,
- origins and destinations are located and distributed in the whole region except in central east part where no products are produced or delivered,
- greater product volume are represented by cement, combustoleo and corn and smaller product volume are represented by wood,

- all origins and destinations except Puerto Juarez are completely connected by both modes of transportation, therefore no other restrictions exist and it is expected that cargo will be distributed according to capacity and costs of each mode (Refer to Figure 2.15),
- distances between origins and destinations, and product volume for each origin – destination pair are shown in Table 2.12,
- one origin and one destination are not located in the southeast, therefore one centroid (no. 10) is defined to simulate the transfer of these products between southeast Mexico and central Mexico,
- corn and cement can be transported in break bulk mode or packed in sacks,
- all railroad terminals have the proper infrastructure to transfer the four products from one mode to another mode,
- these product volumes and these origin destination pairs will be used for the current analysis

Table 2.12
Volume and distances for each origin – destination pair

	No	Origin	No	Destination	Railroad		Truck		Total (ton/wk)
					Distance (km)	Vol (ton/wk)	Distance (km)	Vol (ton/wk)	
Cement (1)	10	Connecting	40	Arriaga	311	3,072	343	9,800	12,872
	10	Connecting	30	Merida	895	413	782	10,983	11,396
	10	Connecting	50	Cd. Hidalgo	617	3,200	583	14,469	17,669
	10	Connecting	60	R. Ayala	128	3,861	224	15,939	19,800
	20	Pino Suarez	50	Cd. Hidalgo	0	0	529	1,075	1,075
	20	Pino Suarez	30	Merida	605	4,384	504	8,253	12,637
	30	Merida	70	Puerto Juarez (Cancun)	0	0	318	13,790	13,790
						14,930		74,309	89,239
	No	Origin	No	Destination	Railroad		Truck		Total (ton/wk)
					Distance (km)	Vol (ton/wk)	Distance (km)	Vol (ton/wk)	
Combustoleo (2)	80	Campeche	30	Merida	173	829	180	0	829
	80	Campeche	100	Valladolid	332	293	337	0	293
	90	Coatzacoalcos	30	Merida	888	5501	716	0	5501
	90	Coatzacoalcos	100	Valladolid	1047	2201	876	0	2201
	90	Coatzacoalcos	70	Puerto Juarez	0	0	1037	20314	20314
						8824		20314	29138
	No	Origin	No	Destination	Railroad		Truck		Total (ton/wk)
					Distance (km)	Vol (ton/wk)	Distance (km)	Vol (ton/wk)	
Corn (3)	110	Salina Cruz	30	Merida	1159	1,022	1,049	3,815	4,837
	110	Salina Cruz	40	Arriaga	201	618	192	1,908	2,526
	120	Progreso	30	Merida	0	0	33	11,137	11,137
						1,640		16,860	18,500
	No	Origin	No	Destination	Railroad		Truck		Total (ton/wk)
					Distance (km)	Vol (ton/wk)	Distance (km)	Vol (ton/wk)	
Wood (4)	60	Roberto Ayala	10	Connecting	128	1,363	224	3,370	4,733
						1,363		3,370	4,733

These volumes for each origin and destination will be entered in the simulation tool used for the optimization.

Figure 2.15: Origins and destinations location

(Source: created in ArcView with data from the Mexican Institute of Transportation)

Information about commercial activity in Mexico and commercial trade treaties are included in Appendix C. This Appendix also includes information about freight distribution, commercial corridors, main products moved in Mexico and main origin destination pairs by mode of transportation in all Mexico. This Appendix is useful to better understand the commercial activity in Mexico and the participation of each mode of transportation.

CHAPTER 3

SIMULATION AND OPTIMIZATION

The transportation industry is a vital part of a nation's economy. An inadequate supply of transportation service could be considered as a bottleneck in nation's economy; therefore, much attention must be given to the transportation mode choice analysis.

Logistics providers usually face the "transportation mode choice" question involving different modes of transportation (i.e. railroad, truck, maritime, air transportation and intermodal transportation).

3.1 Mode Choice Criteria

In the past truck transportation was the choice for most of the logistics providers and shippers. The mode choice was based on only some factors like the possibility of direct access to the final destination and fast delivery. Nowadays other problems like congestion, accidents, pollution and convenience and cost - effective transportation help us to realize that other elements like cost of waiting, environmental issues, company image, warehousing costs and product damage are involved and must be considered.

Common problems of multimodal transportation are competitiveness between all modes of transportation, transportation infrastructure and terminals for an appropriate transfer of products.

Mode choice is very sensitive to price or quality changes (Winston, 1983 and Zlatoper and Austrian, 1989, Bontekoning et al., 2003) and, it appears that timeliness and availability are very important for mode choice (Tsamboulas and Kapros 2000). In general shippers give road transportation high marks, but better marks are given to intermodal rail-truck transportation as compared with railroad transportation (Tsamboulas and Kapros 2000, Bontekoning et al., 2003).

The more highly a firm perceives motor carrier service, the less likely it is to use intermodal transportation. This was the result of studies (Evers and Emerson, 1998, Bontekoning et al., 2003) to measure the influence of an actor's perception of a mode on the mode choice.

"Non users of intermodal transportation have a lower perception of its performance than users". This was the result of a study made by Harper and Evers (1993) and Murphy and Daley (1998). "This result suggests that image and characteristics of a mode of transportation are very important in the mode choice. It can be said that actors do not decide on rational arguments only" (Bontekoning et al., 2003).

Beier and Frick (1978) and Fowkes et al. (1991) found that the loss of quality by using intermodal transportation would be acceptable by shipper only when large discounts are given.

A recent study made by Van Schijndel and Dinwoodie (2000) indicates that congestion on roads can influence Dutch transportation operators to switch from road to intermodal transportation. "The study indicates that most of transportation operators are able to switch to intermodal transportation, but they prefer other solutions for road transportation such as driving during night or dedicated lanes for trucks" (Bontekoning et al., 2003).

According to Meyer et al. (1971), modal choice will depend first on the type of product being shipped and on three important properties: weight of cargo, volume of shipment, and the value of the product.

"Customers usually make mode choices based on the level of service provided to shippers by carriers" (Massachusetts Institute of Technology, 2002). Level of service (LOS) is a complex concept, but the transportation provider needs to understand it as customers perceive it.

The most common level of service variables used for freight transportation are (Massachusetts Institute of Technology, 2002):

- Price
- Travel time

- Service reliability
- Availability of specialized equipment
- Probability of loss and damage
- Information
- Flexibility
- Service frequency
- Shipment size

Sussman (2002) explains with the following figure the relationship between level of service and cost for various freight modes of transportation. The cost structure is a relationship of fixed and variable costs.

Figure 3.1: Relationship between level of service and cost for various modes

(Source: Massachusetts Institute of Technology, 2002)

3.2 Multimodal Multiproduct Simulators

Multimodal Multiproduct Simulators and other logistics software are currently used by transportation operators throughout the world. These tools help them to choose more precisely the best mode or the combination of various modes of transportation and the best or less expensive route for the products transportation. Most of these simulators analyze the volume of products to be moved from one place to another (origin-destination pairs) and the costs of transportation including vehicle operating costs, delay costs and transfer costs for each mode of transportation.

These simulators can also be used to analyze the freight transportation behavior and its current situation (freight flows, costs, capacities, logistics chains, type of products and products volume) in a country or in certain region, and how this situation can be improved or optimized using the same infrastructure. The results of this type of analysis will be also useful to plan ahead and to prioritize the construction of transportation infrastructure.

Some of these simulators or tools currently used by transportation operators are:

- **i2 Technologies applications.**

These technologies applications are used by the Canadian National Railway for the analysis of customer's supply chain network.

"Using advanced supply chain modeling and optimization algorithms, Supply Chain Strategist provides a tool that we work with to create a framework to optimize a distribution network, structure, and modal options while addressing cost and service constraints. Through this type of network analysis we typically identify opportunities that will save 5 - 10% of total supply chain costs" (Canadian National Railway, 2004).

Some of the factors considered in this analysis are: location of distribution centers and transload facilities, choice of transportation mode, and total supply chain costs (Canadian National Railway, 2004).

- **Promodi**

This mode choice tool was developed to support the transportation mode decision process. It was developed based on the results of a survey organized in 1999 and 2001 among shippers and logistics providers located in Flanders, Belgium. "These surveys examined the point of view of the shipper concerning the transportation mode choice" (Vannieuwenhuysen et al., 2002).

These surveys show the measures taken by the industry to manage the transportation problem, the transportation mode choice criteria and the transportation mode performance.

The study shows that almost 80 percent of the companies already take measures to improve and reduce costs of their freight flows. Consolidation is the most common measure taken by companies (44 percent), and outsourcing of transport and logistics activities is the second measure taken by companies (35 percent). Refer to Figure 3.2.

Figure 3.2: Measures taken by the industry to control the mobility problem
(Source: Vannieuwenhuyse et al., 2002)

Transportation cost and reliability are the most important factors considered by companies to decide which mode of transportation is going to be used (Vannieuwenhuyse et al, 2002). However, there are other important factors that sometimes can be more important for

other companies or in special situations. Table 3.1 shows the results for the mode choice survey based on eleven factors.

Table 3.1
Transportation Mode Criteria
 (0 totally unimportant, 5 neutral, 10 very important)

Factor	Definition	Weight
1	Transportation cost	Direct cost of transportation, e.g., fuel, driver's wages,...
2	Reliability	Ability to respect the promised delivery date.
3	Flexibility	Ability to adapt to changing customer requirements and circumstances.
4	Transportation time	Duration of the overall transportation process (from door-to-door).
5	Safety	Probability of avoiding damage and loss of quality of the goods.
6	Capacity	Remaining capacity available.
7	Density of network	Availability of (alternative) links.
8	Regulation and legislation	Set of rules, obligations, customs formalities, etc.
9	Impact	Impact and control potential on goods flow.
10	Image	Company image with respect to environment, safety, etc.
11	Strategic elements	Considerations of strategic nature.

Source: Vannieuwenhuyse et al., 2002

Road transportation still has the best overall performance score between various modes of transportation. Performance scores for each mode of transportation for different factors are shown in Table 3.2.

Table 3.2
Performance scores for each mode of transportation
 (0 totally unimportant, 5 neutral, 10 very important)

Performance scores		Road haulage	Rail transport	Inland waterway transport	Intermodal transport
Factor					
1	Transportation cost	7.51	6.62	7.50	7.38
2	Reliability	7.53	5.45	6.31	6.68
3	Flexibility	7.46	4.59	6.00	6.21
4	Transportation time	5.23	6.31	6.81	6.54
5	Safety	6.58	6.93	7.62	7.25
6	Capacity	6.17	6.28	6.58	6.73
7	Density of network	7.31	5.03	6.65	6.64
8	Regulation and legislation	6.74	5.45	6.73	6.54
9	Impact	6.56	5.90	6.31	6.18
10	Image	6.17	5.62	5.73	5.75
11	Strategic elements	5.85	5.90	6.31	6.07

Source: Vannieuwenhuyse et al., 2002

“With this tool the user gets a suggestion of the transportation mode ranking according to his own performance perception, followed by a benchmark of his perception to the general (average) perception. If the chosen transportation mode does not match the suggested one, this is a sign for the shipper or the logistics provider to rethink his transportation mode choice” (Vannieuwenhuyse et al., 2002)

- **STAN: Strategic Transportation Analysis (INRO Consultants Inc.)**

STAN is a multimodal multiproduct simulator that is commonly used for strategic studies of national and regional freight transportation. It can be used for the representation of transportation infrastructure and for the modeling of multimodal and multiproduct freight transportation activities or distribution systems. This simulator basically contains transportation networks, matrices (origin-destinations, costs) and functions that can be modified interactively or by using batch files (INRO Consultants Inc., 2002).

STAN is currently used in 17 countries by 50 organizations. STAN users include cities, metropolitan areas, consulting firms and universities (INRO Consultants Inc., 2002).

Before describing data input procedures and data collection, it is important to better understand the simulation tool that was used to perform the optimization.

3.3 STAN Characteristics

The transportation simulation tool STAN (Strategic Transportation Analysis) provides a flexible and general framework for representing the infrastructure

and modeling the activities of multimodal and multiproduct freight transportation or distribution systems (INRO Consultants Inc, 2002).

"STAN is a decision support system which provides uniform and efficient handling of data procedures, including complete data consistency validation upon entry. Its data bank is structured to permit the simultaneous analysis of several planning alternatives." (INRO Consultants Inc, 2002).

The STAN data bank contains all the information necessary to perform a strategic analysis of freight transportation. It contains representations of the transportation system selected for the analysis, the demand in the zone and models of the socioeconomic criteria that explain the distribution of the demand over the network (Refer to Figure 3.3).

Figure 3.3: STAN Data Bank
(Source: INRO Consultants Inc., 2002)

In STAN, all network elements are structured in a well defined hierarchy according to the following figure.

Figure 3.4: Hierarchy for network elements

(Source: INRO Consultants Inc., 2002)

When a new network element is added, all elements related with this new element must already be defined, and an element can be deleted only when no elements lower in the hierarchy refer to it.

One of the first steps in developing the model is to establish the study region and how the region will be subdivided into smaller regions that represent the supply and demand zones. In STAN these regions or zones are represented by dummy nodes defined as centroids. These do not represent any physical facility. All traffic from and to the zone originates and terminates at the centroids.

As shown in Figure 3.4 the network in STAN is formed by various elements. These elements are: modes, products, base network (nodes and links), transfers, vehicles and function sets.

3.4 Theoretical Foundation of Simulation/Optimization Method

The components of the Simulation – Optimization modeling framework are shown in Figure 3.5. As for the process of macrosimulation and optimization, please see Figure 3.6.

The stopping criteria mentioned in Figure 3.6 may be a maximum number of iterations or a certain tolerance on the relative gap. The relative gap is an estimation of the difference between the current assignment and an optimal assignment in which all multimodal paths used have the same marginal costs. It is based on the value of the objective function and a best lower bound for the optimal value at the current iteration (INRO Consultants Inc., 2002).

The acronym STAN is derived from “Strategic Transportation Analysis”. The modeling approach used to address this issue was developed in the late 80’s at the Center for Research on Transportation (C.R.T.) of the University of Montréal and since 1988, technical support and development has been provided by INRO Consultants (INRO Consultants Inc., 2002).

Figure 3.5: Components of Simulation-Optimization Modelling Framework

Figure 3.6: Macrosimulation – Optimization Process

3.4.1 Macroscopic Simulation Model

STAN is both a general modeling and analysis framework and an interactive graphic computer system offering a comprehensive software designed to perform strategic analysis of multimodal multiproduct transportation system. As a modelling framework, STAN offers capabilities to represent the main functional elements of such systems. These are transportation infrastructure, supply and demand, costs as well as the capabilities to simulate the associated traffic behavior. On the other hand, STAN as the computer system is formed by a series of modules used to input, modify, display and output the resultant information (Crainic et al., 1993).

STAN was designed for freight transportation analysis and planning, and its design is based on the design of EMME/2, which is an interactive graphic method for multimodal urban and regional planning for the transportation of persons (Crainic et al., 1993).

EMME/2 was specifically designed for multimodal networks (EMME is a bilingual acronym for Équilibre Multimodal, Multimodal Equilibrium) where all the considered modes of transportation can be modeled in an integrated way (INRO Consultants Inc., 2002).

3.4.2 Network Optimization Model

The network optimization model used to simulate network flows in STAN is a nonlinear multimode multiproduct assignment formulation that minimizes the total generalized system costs of moving the considered products, from origins to destinations, using the permitted or specified modes of transportation (Guélat, Florian and Crainic, 1993).

For each product and demand matrix, one or several multimodal paths are chosen for demand between each origin-destination pair such as to minimize the total generalized cost of the transportation system (INRO Consultants Inc., 2002).

The marginal cost of a path, given the current flow distribution of the considered products, represents the variation in the total cost of the system due to a change of one unit in the flow that travels over the links and transfers of the path (INRO Consultants Inc., 2002).

The total generalized cost function is the sum of operating costs, delay costs and other costs over all products, links and transfers. The assignment in STAN is based on minimizing the total generalized cost (INRO Consultants Inc., 2002).

$$\text{MIN } F = \sum \text{operating costs} + \sum \text{delay costs} + \sum \text{other costs}$$

The multimode multiproduct assignment is solved by an adaptation of the linear approximation method established by Frank & Wolfe in 1956, with a decomposition of the problem by product (Refer to Appendix D). The total cost is the sum of the total product cost for all products. The main idea behind the assignment, is to solve x smaller problems, where x is the number of products, by assigning one product at a time, and considering the others as fixed (INRO Consultants Inc., 2002).

The initial solution of the multimode multiproduct assignment may be an “all or nothing” solution with free flow marginal costs or the current solution of an assignment that has already been carried out (INRO Consultants Inc., 2002).

“For each product, a subset of modes which are permitted for a given assignment may be specified. Furthermore, the origin – destination demand matrix for a given product may be decomposed, and a particular subset of permitted modes may be defined for each resulting origin – destination matrix as well. Predefined mode choices may thus be introduced into the system. It is always possible, of course, to assign all products to all modes, based exclusively on performance measures”. (Guélat, Florian and Crainic, 1993).

There is no default mode choice model built into STAN and functions are used to specify the criteria used to determine how traffic is moved over the

network. These functions may include factors such as travel cost, congestion phenomena, environmental preoccupations, energy prices, or any other performance measure.

Capacity restrictions and congestion problems on different modes of transportation are considered in STAN by using volume/delay functions. These functions are usually incorporated (user defined) into the delay cost component of the generalized cost function (Florian and Crainic, 1989; Crainic, Florian and Leal, 1990).

The assignment is carried out by using a total generalized cost function which is a weighted combination of up to three functions that correspond to the three components of the function sets.

3.5 Data Collection

All necessary data used for this analysis as well as their sources are described in the following section.

3.5.1 Products

In STAN, goods are referred as products. A product may be a single good or an aggregation of commodities with similar characteristics.

All information regarding products movement and their characteristics was obtained from the Chiapas-Mayab Railroad and from statistics published on the internet by the Mexican Transportation Institute and by the Ministry of Communications and Transports in Mexico. Products moved in the region and products selected for this analysis are described in Chapter 2.

3.5.2 Modes of Transportation

A mode is any mode of transportation that has its own characteristics. A mode may represent an actual transportation mode or a service. It can also represent terminals like ports or intermodal terminals.

The modes included in the analysis were selected according to the products origin and destination. In STAN the modes were entered interactively and no further information was necessary to input.

3.5.3 Base Network

The base network is the representation of the transportation infrastructure to model. In STAN, this representation is made up of modes, nodes, links and transfers.

A node is a vertex of the graph representing the network. A node may represent main road intersections, cities or transportation facilities such as

ports, rail yards, airports, transfer points or production centers. A node has the following standard attributes:

i	node number (1-999999) used to identify the node elsewhere in STAN
xi	X-coordinate
yi	Y-coordinate
ui1,ui2,ui3	user defined node data (optional)
lab	node label (optional)

A link is a mode-specific, directional connection between two nodes of the network. Parallel links (links connecting the same two nodes in the two directions) are allowed and the link which runs in the reverse direction is called the reverse link. A link has the following standard attributes:

i	node number of starting node of link
m	mode letter of link mode
j	node number of ending node of link
len	link length in length units
typ	link type (user defined); number between 1 to 999
fct	link function set number
cap	link capacity
beta	coefficient that can be used in link functions
phil	link "phi" coefficient

mset mode set: subset of modes sharing the same link capacity
 ul1,ul2,ul3 user defined link data (optional)

The southeast Mexico base network was created transforming ArcView shapefiles provided by the Mexican Transportation Institute into STAN input files. A formal request for this data was made and approved by this institute.

The shapefiles provided are:

- main highways (toll and free),
- railways,
- maritime ports,
- airports,
- railroad terminals,
- intermodal and multimodal terminals,
- highway nodes and,
- main cities (Refer to Figure 3.7).

Figure 3.7: Southeast Mexico ArcView shapefiles

(Source: Created in ArcView with data provided by the Mexican Institute of Transportation)

These shapefiles also contain other important information that was used for highway and railway link attributes like capacity, number of lanes, length, pavement and railway conditions, and other characteristics.

According to these shapefiles, the network length considered in this analysis is distributed as follows: **5 215** km of free roads, **787** km of toll roads and **1926** km of railways.

Once the shapefiles were received, they were sent to INRO Consultants Inc. in Montreal, Canada for proper transformation and returned to the author in STAN format preserving the original ArcView georeferenced data.

Some node and link attributes were automatically created when ArcView data was transformed into STAN input files. Other attributes were entered interactively with data obtained from:

- ArcView table of attributes included in shapefiles provided by the Mexican Institute of Transportation,
- the Ministry of Communications and Transports Mexico,
- the Chiapas-Mayab Railroad,
- the Mexican Transportation Institute and other papers published by this Institute.
- the Bank of Mexico,
- Truck Trailer retailers, and
- Web pages.

Table 3.3
Highways table of attributes

Nombre	Longitud (A)	Modo	Capacidad	Ruta	Clasificac	Camión	Terreno	Medio	Oper
JARALILLO-AGUASCALIENTES	27.000	CARRETERO	104860	45	CARRETERA 4 CARRILES (C4)	4	LOMERIO	RURAL	FEDEF
T AGUASCALIENTES-AGUASCALIENTES	8.000	CARRETERO	33572	70	CARRETERA 2 CARRILES (C2)	2	LOMERIO	RURAL	FEDEF
JALPA-T AGUASCALIENTES	82.000	CARRETERO	33572	70	CARRETERA 2 CARRILES (C2)	2	LOMERIO	RURAL	FEDEF
T AGUASCALIENTES-TEOCALTICHE	65.000	CARRETERO	33572	9	CARRETERA 2 CARRILES (C2)	2	LOMERIO	RURAL	FEDEF
AGUASCALIENTES-TRONCOSO	101.000	CARRETERO	33572	45	CARRETERA 2 CARRILES (C2)	2	LOMERIO	RURAL	FEDEF
AGUASCALIENTES-OJUELOS	86.000	CARRETERO	64057	70	CARRETERA 2 CARRILES (C2)	2	PLANO	RURAL	FEDEF
T SAN MIGUEL-EL SAUZAL	6.000	AUTOPISTA	112994	1	AUTOPISTA 4 CARRILES (A4)	4	LOMERIO	RURAL	FEDEF
EL SAUZAL-ENSENADA	8.000	AUTOPISTA	112994	1	AUTOPISTA 4 CARRILES (A4)	4	LOMERIO	RURAL	FEDEF
EL SAUZAL-TECATE	100.000	CARRETERO	33572	3	CARRETERA 2 CARRILES (C2)	2	LOMERIO	RURAL	FEDEF
ENSENADA-LAGUNA DE CHAPALA	414.000	CARRETERO	33572	1	CARRETERA 2 CARRILES (C2)	2	LOMERIO	RURAL	FEDEF
LA MISION-T SAN MIGUEL (CUOTA)	33.000	AUTOPISTA	188349	1	AUTOPISTA 4 CARRILES (A4)	4	PLANO	RURAL	CAPUF

Source: Created in ArcView with data provided by the Mexican Institute of Transportation

3.5.4 Transfers

A transfer is an intermodal movement defined at a node to permit products to be moved from one modal link to another (different) modal link. In STAN, transfers are represented by an ordered pairs of links (I1, I2) with a common node, the at-node. L1 is referred to as the incoming link and I2 is referred as the outgoing link of the transfer. A transfer is identified by at-node j, from-node i, from-mode m, to-node k and to-mode n, or (j, I, m, k, n). (INRO Consultants Inc, 2002).

The base network or multimodal network consists of nodes and the modal and directed links that join the nodes. Transfers may be defined at nodes.

In STAN, a transfer has the following attributes:

- j transfer node
- i I-node of incoming link, or from-mode

m	mode of incoming link, or from-mode
k	J-node of outgoing link, or to-node
n	mode of outgoing link, or to-mode
fct	transfer function set number, 0=free transfer
phit	transfer "phi" coefficient
ut1,ut2,ut3	transfer user data

Transfers location and transfers costs were entered interactively in STAN with data obtained from:

- ArcView table of attributes included in shapefiles provided by the Mexican Institute of Transportation,
- the Chiapas-Mayab Railroad,
- the Mexican Transportation Institute and other papers published by this Institute.

3.5.5 Vehicles

In a transportation network, vehicles are the instruments which transport goods across the network. In STAN a vehicle is the basic unit used to transport freight, and vehicles are part of the network data. A vehicle is defined for each product and for each mode of transportation, and sometimes vehicles can be grouped into convoys.

In STAN, a vehicle has the following attributes:

Product number	number defined to refer to a product
Mode identifier	letter used to identify the modes
wbyveh	product weight by vehicle, the usual load of the vehicle (ton)
vehwgt	vehicle weight (when empty)(ton)
conwght	convoy weight (ton) (maximum number of cars)
uv1, uv2, uv3	three user defined vehicle data (optional)

Product weight and vehicle attributes like vehicle weight and convoy weight were entered interactively in STAN with data provided by:

- the Chiapas-Mayab Railroad,
- the Mexican Transportation Institute and other papers published by this Institute.

3.5.6 Functions

A function is a data structure containing an algebraic expression which describes a functional relationship. Functions are associated with product movements on the links and through the transfers of a network (INRO Consultants Inc., 2002). Functions measure network performance on each link and transfer like travel costs, delay costs or time.

The measure associated with each unit or product flow traveling over a link or through a transfer is cost. Cost could be based on distance, time or some other measure like money. Generalized cost is the most common type of cost considered in STAN. Generalized cost is the sum or combination of three different cost components over all products, links and transfers. These costs components are: operating costs, delay costs and other costs. The user must define the functions that will be used for these components (INRO Consultants Inc., 2002).

All data necessary to calculate costs (vehicle operating costs, delay costs and transfer costs) were obtained from:

- the Ministry of Communications and Transports Mexico,
- the Chiapas-Mayab Railroad,
- the Mexican Transportation Institute and other papers published by this Institute.

- the Bank of Mexico,
- ArcView table of attributes included in shapefiles provided by the Mexican Institute of Transportation

3.5.7 Origin – Destination Matrices

In STAN all origin-destination demand data for all products is stored in matrices. Matrices are the standard way of storing all data related to zones, and in this analysis a full origin-destination matrix for each product was entered interactively.

Origin-destination pairs and demand volume for each product were determined before in Chapter 2 with data obtained from the Mexican Transportation Institute and from the Chiapas-Mayab Railroad.

CHAPTER 4

NETWORK MODELLING AND CALIBRATION

The methodology to perform the simulation is explained in this chapter.

4.1 Creating scenario

4.1.1 Centroids Location

The southeast region was subdivided into twelve smaller regions that represent the supply and demand zones. These twelve centroids were defined according to the origins and destinations of the four products selected for the analysis as mentioned before in Chapter 2. In other words, these twelve centroids represent the origin and destination for all products selected for this simulation - optimization.

It is important to mention that centroids were created first in ArcView and then created in STAN. (Refer to Figure 4.1)

Figure 4.1: Centroids Location

(Source: Created in ArcView with data from the Mexican Transportation Institute)

4.1.2 Products

Once the centroids were defined, the next step was to input the products selected for the analysis. As mentioned before in Chapter 2, the products selected for the optimization are: Cement, Combustoleo, Corn and Wood (Refer to Table 4.1). These four products were entered interactively in STAN.

Table 4.1
Product Table

STAN Module:	2.02	Date:	04-10-31 21:19	User:	S050/CARLETON..CVA
Project:	STAN	/project title			
Scenario 1000:	STAN Network from GIS				

P R O D U C T T A B L E					

-----	Product	-----	user defined data	-----	
		up1	up2	up3	
1	Cement	.000	.000	.000	
2	Combustoleo	.000	.000	.000	
3	Corn	.000	.000	.000	
4	Wood	.000	.000	.000	

4.1.3 Modes of transportation

The next step in the process was to establish the transportation modes for the analysis. The products selected for the analysis are moved through roads and railways only, therefore, the transportation network consists of a system of free roads, toll roads and railways. In addition, to model access from the network to the zone a connector mode is used. Airports were not included as a mode of transportation.

In STAN, to differentiate all modes of transportation between each other, each mode is identified with a letter, a line code and a color code. This will also help to easily input and change information for each mode and to manipulate plot and graphic characteristics. These modal characteristics for the current analysis are shown in Table 4.2.

Table 4.2
Mode Table

STAN Module: 2.01		Date: 04-10-07 15:39		User: SOSO/CARLETON..CVA					
Project: STAN		/project title							
Scenario 1000: STAN Network from GIS									

M O D E T A B L E									

Mode	Description	Line code	Color code	phim	-- user defined data --	um1	um2	um3	int. no.
a	Toll Roads	1	3	1.000	.000	.000	.000	.000	1
c	Free roads	2	3	1.000	.000	.000	.000	.000	2
n	Connector	7	4	1.000	.000	.000	.000	.000	3
r	Railway	5	5	1.000	.000	.000	.000	.000	5

4.1.4 Base Network

The southeast Mexico base network was created transforming ArcView shapefiles provided by the Mexican Transportation Institute into STAN input files. Links represent highways and railways and nodes represent highway intersections and railroad terminals.

Once the base network was transformed into STAN input files it was plotted and compared with updated highways and railways maps obtained from the Ministry of Communications and Transports and from the Chiapas-Mayab

Railroad. As a result of this comparison some important changes became necessary and new links and nodes had to be created.

Some of the most important changes that were done are:

1. A toll highway connecting Coatzacoalcos-Nuevo Teapa in Veracruz with Tuxtla Gutierrez in Chiapas was added.
2. A toll highway connecting Tuxtla Gutierrez with San Cristobal de las Casas in the state of Chiapas was added.
3. Some corrections for rail links were done because they were connecting wrong nodes.
4. All rail nodes were verified and some of them were deleted because service is no longer available at that station (node).
5. Nodes where railroad and highway links coincide were verified. It was necessary to reconnect them because their nodes were independent of each other and no transfers could possibly be built (a common problem when ArcView shapefiles are transformed into STAN input files).

The network length considered in this analysis is distributed as follows: **5215** km of free roads, **787** km of toll roads and **1926** km of railways

All changes were done interactively in STAN and the final version of STAN base network is shown in Figure 4.2.

Figure 4.2: STAN base network

(Source: Created in STAN with data from the Mexican Transportation Institute)

It is important to mention that once the base network was created and all changes were made, all nodes, links and centroid attributes for each mode of transportation were entered interactively in STAN.

4.1.4.1 Nodes

Nodes represent highway intersections and railroad terminals. Each node is represented in STAN by a node number and X and Y coordinates. Both node number and X and Y coordinates were automatically created when ArcView data was transformed into STAN input files. Other optional data (ui1, ui2, ui3 and lab) was not used in this analysis, therefore no changes were made and no further information was necessary to input.

A total of 80 regular nodes for highways and railways were created for this analysis.

4.1.4.2 Links

Links represent highways and railways in the network. A link is a mode-specific, directional connection between two nodes of the network.

A link has the following standard attributes:

i	node number of starting node of link
m	mode letter of link mode
j	node number of ending node of link
len	link length in length units
typ	link type (user defined); number between 1 to 999

fct	link function set number
cap	link capacity
beta	coefficient used in composite keywords
phil	link phi coefficient
mset	mode set: subset of modes sharing the same link capacity
ul1,ul2,ul3	user defined link data (optional)

Some links attributes were automatically created when ArcView data was transformed into STAN input files, other attributes were defined as follows:

- a) The link length (len) was obtained from ArcView attributes tables and entered in STAN interactively for each link and for each mode of transportation in kilometer units.
- b) Because no other use was defined for link "typ" in this analysis, a number 1 was entered for all links.
- c) A link function set number (fct) was entered to point the set of functions used to determine the cost of moving one unit of products through a link. There are four different links in the base network and each link is identified with a different function set number. (Refer to Table 4.3.).

Table 4.3
Link function set number

Link Type	Function set number
Road links: toll roads	1
Road links: free roads	2
Rail links	3
Connector links	4

Because the cost difference of using toll and free roads, two different function set numbers were created. This will be discussed later when function sets for each product and each component are entered.

- d) Link capacity "cap" usually represents the physical capacity of the link and can be represented by: maximum total tonnage, number of vehicles or number of convoys. In this analysis capacity was defined as number of vehicles/day (in both directions) for road links, and number of trains/day for rail links. Road capacity data was obtained from ArcView attributes tables provided by the Mexican Transportation Institute and rail capacity data was obtained from the Chiapas-Mayab railroad in Mexico. Both capacities were entered interactively for each link and for each mode of transportation.
- e) For this study the "beta" coefficient is not going to be used, therefore no value was entered.

- f) The mode set "mset" is a list of modes of parallel links that share the same infrastructure or link capacity with the current link. For this case roads connectors and rail link capacity is not shared, therefore, a # is entered.

Other link attributes such as "ul1", "ul2", "ul3" and "phi" coefficient were entered according to particular characteristics of each mode of transportation.

4.1.4.2.1 Road Links

Besides general attributes mentioned before, other particular link attributes were used for road links in this analysis.

- a) The "phi" coefficient as the beta coefficient can be used for general link functions. In this analysis the phi coefficient was used to store the cost of toll roads and toll bridges in highways. In this analysis, toll road cost and the toll bridge cost were obtained from the Ministry of Communications and Transports web page (<http://www.sct.gob.mx/>) and all values were entered in Mexican Pesos (Refer to Table 4.4, Figure 4.3 and Figure 4.4).

For free roads links and connector links these coefficients were not used and a value of zero was assigned.

Table 4.4
Toll roads cost

Toll Road	Length (km)	Toll Cost (MXP)
Acajucan - Cosoleacaque	40	83.5
Arriaga - Huixtla	204.5	266
Las Choapas - Ocozocoautla	198	326
Champoton - Campeche	39.5	103
Kantunil - Cancun	231.34	978
Minatitlan - Nuevo Teapa	29	53
Cosoleacaque - Minatitlan	10	15
Toll Bridges	Length (km)	Toll Cost (MXP)
Coatzacoalcos	1	40
Ing. A. Dovali J.	1.27	40
Usumacinta	0.35	57
Grijalva	0.25	57

Source: Created with data from the Ministry of Communications and Transports

Figure 4.3: Toll roads location

(Source: Created in STAN with data from the Mexican Transportation Institute)

Figure 4.4: Toll bridges location

(Source: Created in ArcView with data from the Mexican Transportation Institute and the Ministry of Communications and Transports Mexico)

- b) The ul1, ul2 and ul3 attributes were used to input important data necessary to calculate transportation costs (vehicle operating costs and delay costs). "Ul1" was used to input vehicle operating costs, and "ul2" and "ul3" attributes were used to calculate a congestion factor necessary to calculate delay transportation costs. For road links "ul2" was used to store the Annual Average Daily Traffic (AADT) plus two times the AADT for buses on each link ($AADT + 2 \text{ Buses AADT}$), and "ul3" was used to store the AADT for trucks on each link.

No other link attributes were necessary to input to run the assignment.

The next step in the process was to calculate the Vehicle Operating Costs (trucks) for road transportation which procedure is described in the following part.

Vehicle Operating Costs (Trucks) (ul1 attribute)

Vehicle characteristics and attributes used for the analysis are discussed later in this chapter. However, before describing Vehicle Operating Costs (VOC) it is important to mention some basic characteristics of the vehicles selected for this analysis. The truck selected for this analysis is the International 9200i truck trailer type T3-S2 with three axles (tractor trailer of 40 feet, two axels). This truck trailer is the typical vehicle used in Mexico for freight transportation analysis and simulation optimization studies. Refer to Appendix E.

Vehicle operating costs were calculated with a model created in 2002 by Arroyo and Aguerrebere from the Mexican Transportation Institute (Arroyo et al., 2002). This model was created to calculate vehicle operating costs for a typical vehicle used for commercial and private intercity transportation in Mexico. This model considers the geometric alignment, pavement surface conditions and their effects on the vehicle operating costs.

According to information provided by Arroyo et al. this model is based on mathematical models developed by the World Bank and published in 1987, which gave origin to the software, called Vehicle Operating Costs (VOC). Additionally, Arroyo and Aguerrebere explained the following: "the software

developed for this work (called VOCMEX) is an adaptation of the Vehicle Operating Costs software (VOC). The VOCMEX considers the technical characteristics of vehicles running on Mexican roadways as well as the models with the new mathematical expressions developed for the HDM-4 software (Highway Development and Management Tools, version 1, United Kingdom, 2000) by Bennett and Paterson (Bennett et al., 2000)".

With the use of the World Bank models mentioned above through the VOCMEX and selected vehicle technical characteristics as well as vehicle and components prices, a set of graphics was built. Through these graphics, operating costs of seven different types of vehicles under various conditions (geometric alignments and pavement surface conditions) can be estimated without using the software.

The characteristics considered for the development of this model are: pavement surface conditions, International Roughness Index, roads slope, trucks weight, load capacity, speed, power, number of kilometers conducted per year, average useful service life, unit cost, number of tires per vehicle and tires cost.

The formula developed by Arroyo et al. (2002), to calculate the vehicle operating costs is the following:

$$\text{COA} = \text{Fb} \times \text{CB} \dots \dots \dots (4.1)$$

Where;

COA: operating cost (\$/km)

Fb: basic operating costs factor (obtained from the graphics generated in the model according to the type of vehicle, type of terrain and pavement conditions).

CB: basic vehicle operating costs according to the type of vehicle (generated in the model).

The procedure to calculate the basic operating costs factor “Fb” and the basic vehicle operating costs “CB” are described in the following part:

1. **Basic operating costs factor:** According to the type of terrain (level, rolling, mountainous) and the International Roughness Index in each link, an “Fb” factor was selected from the appropriate graphic for a T3-S2 Truck (Figure 4.5). The International Roughness Index was selected based on each link pavement conditions (good, fair and bad) according to the IRI Roughness Scale created by Sayers et al., (1986). (Refer to Figure 4.6 and Table 4.5.)

Figure 4.5: Fb graphic for T3-S2 trucks

(Source: Arroyo et al., 2002)

Figure 4.6: IRI Roughness Scale created by Sayers et al., 1986

(Source: Washington Asphalt Pavement Association, 2004)

Table 4.5
IRI selected for pavement conditions

Conditions	IRI
Good	2
Fair	4
Bad	6

Pavement conditions were obtained from a study made by Perez et al., (2001) in Mexico. This study was made to identify pavement conditions of all highways in Mexico in 2001 and pavement conditions were classified by the authors according to the International Roughness Index in good, fair and bad conditions. These study results for southeast Mexico are shown graphically in Figure 4.7.

Figure 4.7: Pavement conditions in southeast Mexico
 (Source: Perez et al., 2001, Mexico)

Terrain types for highways in southeast Mexico were obtained from the Mexican Transportation Institute and included in ArcView attributes tables from shapefiles provided to create the base network.

Highway terrain types are divided in three categories: level, rolling and mountainous, and their distribution and location for highways in southeast Mexico are shown in Figure 4.8.

Figure 4.8: Terrain type for highways in southeast Mexico
(Source: Perez et al., 2001, Mexico)

2. **Basic vehicle operating cost (CB)** are the costs of a vehicle that travels on a level and straight highway (grade=0) with very good pavement conditions (IRI=2 m/km). These costs can be obtained with the sum of the results of multiplying the consumption of one truck in one kilometer by their respective unit costs. The consumption estimates for the truck selected for this analysis (T3-S2) were obtained from Arroyo et. al., (2002) and are shown in Table 4.6.

It is important to mention that this model was developed in the year 2002, using unit costs of 2001; therefore, it was necessary to update these unit costs to the year 2003. This update was completed using the Mexican Inflation Index for each product (see Table 4.7) for the year 2003 and verifying some prices for these products through the Internet or by phone directly with the retailer. The costs of all products were updated in Mexican Pesos and do not include taxes or other surcharges. Refer to Table 4.8.

Table 4.6
Truck consumptions for a T3-S2 truck (1000 vehicles/km)

Concept	Unit	Consumption
Diesel consumption	liters	480.64
Lubricants consumption	liters	5.45
Tires consumption	number of tires	0.38
Driver labour time	hours	11.63
Maintenance labour	hours	30.48
Maintenance parts	% of new truck	0.27
Depreciation	% of new truck	0.05
Interest (Rate 10%)	% of new truck	0.02

Source: Arroyo et al., 2002

Table 4.7
Inflation index by product

Period	2000	2001	2002	2003	Dec 2000- Dec 2003
Inflation	8.96	4.40	5.70	3.98	14.74
Products					
Gasoline	10.15	6.94	0.81	4.44	12.59
Diesel	10.16	6.32	4.55	3.12	14.63
Electricity residential	9.85	8.54	34.97	7.04	56.80
Electricity business	4.49	1.20	12.21	10.17	25.09
Phone services (residential)	3.85	3.98	-0.03	0.03	3.98
Office lease	7.73	6.23	6.50	4.71	18.47
Oil and lubricants	17.41	12.73	0.11	3.74	17.06
Tires (automobile)	6.99	8.29	0.52	1.10	10.05
Tires (trucks)	3.42	10.09	2.46	1.65	14.66
Buses	0.31	-2.90	16.00	12.12	26.29
Truck trailers	0.52	-1.69	11.29	10.47	20.86
Engines	1.62	-1.36	7.02	7.35	13.33
*Source: Banco de México (Banxico)					

Source: Transporte Siglo XXI magazine, 2004

Table 4.8
Updated unit costs (for 2003 in MXP)

Type of Truck	Long haul trucks (T3-S2)
Brand	International 9200i
Cost	1,061,437.70
Type of tires	1100-20.00 normal
Costo	1,418.22
Diesel cost (l)	4.4348
Lubricants cost (l)	11.76
Driver salary (hr)	48.78
Maintenance labour (hr)	34.15
Annual interest rate (%)	10
Indirect costs (veh-km)	0.76

Source: created with data from Arroyo et al., 2002 and Transporte Siglo XXI magazine, 2004

Once the unit costs were updated, they were multiplied by the truck consumptions and the basic vehicle operating cost was obtained (**CB=8.8104 MXP/km**). (CB=0.88 CND/km, CB=0.74 USD/km)

Vehicle operating costs were obtained using the formula mentioned before (**COA = Fb x CB**) and the obtained results for each link were entered interactively in STAN.

Transportation Delay Costs (ul2, ul3)

The "ul2" and "ul3" attributes are used to store data necessary to create a congestion factor that will be used to calculate transportation delay costs. The value of this congestion factor will depend on the AADT for cars, buses and trucks that are traveling through the highways included in the transportation network of this analysis.

Attribute "ul2" was used to input the Annual Average Daily Traffic (AADT) plus two times the AADT for buses on each link ($AADT + 2 * \text{Buses AADT}$), and "ul3" was used to store the AADT for trucks on each link. The Annual Average Daily Traffic was obtained from a study made by the Ministry of Communications and Transports for all highways in Mexico in 2001 and published in another study made by Jimenez et al., (2001).

The results of the study made by the Ministry of Communications and Transports show that the average AADT for highways in southeast Mexico is equal to 1928 vehicles. The 80 percent of these vehicles are represented by cars; the 5 percent are represented by buses and the 15 percent are represented by freight trucks.

Figure 4.9 shows the AADT for highways in southeast Mexico ordered in five different ranges and represented in a map with different line widths.

Figure 4.9: AADT for highways in southeast Mexico
(Source: Perez et al., 2001, Mexico)

Highway routes in southeast Mexico with the greater AADT and its distribution (cars, buses and freight trucks) were also identified in the study made by Jimenez et al. (2001) and are shown in Table 4.9.

The AADT for highway routes shown in Table 4.9 was included in the analysis and for all other highway routes not included in Table 4.9 the average AADT mentioned before was selected.

Table 4.9
AADT for some highway routes in southeast Mexico

Highway Routes	State	Length (km)	AADT (veh)	AADT Distribution		
				Cars (%)	Buses (%)	Freight Trucks (%)
Coatzacoalcos - Villahermosa	Tabasco	129.7	9,411	67.0	8.0	25.0
Merida - Progreso	Yucatan	35	7381	73.5	6	20.3
Coatzacoalcos - Salina Cruz	Oaxaca	161.9	5987	74	7.6	18
Villahermosa - Comalcalco	Tabasco	50.7	5956	75.4	6.3	18.3
Felipe Carrillo Puerto - Puerto Juarez	Quintana Roo	226	5712	81.9	5.4	12.6
Tapanatepec - Tuxtla Gutierrez	Chiapas	159	4794	72.9	5.9	21.1
Malpaso - El Bellote	Chiapas	185.5	4592	69.7	8.6	21.6
Tapanatepec - Talisman	Chiapas	310.8	4330	74.7	7.2	18.2
La Ventosa - San Pedro Tapanatepec	Oaxaca	91.8	4024	79.8	3.7	16.5
Villahermosa - Francisco Escarcega	Campeche	297	3978	72.7	5.6	21.7
Villahermosa - Cd. Del Carmen	Campeche	163.2	3828	73.1	6.3	20.6
Campeche - Merida	Campeche	192.2	3566	77.7	5.2	16.9
Merida - Puerto Juarez	Quintana Roo	321.4	3417	80.7	5.1	14
Campeche - Tenabo	Campeche	40	3370	75.7	6.6	17.7
Tuxtla Gutierrez - Cd. Cuauhtemoc	Chiapas	256	3286	75.4	4.9	19.7
Villahermosa - Escopetazo	Chiapas	259	3185	75.1	6.3	18.4

Source: created with data from Jimenez et al. 2001, Mexico

It can be observed that only some highway corridors manage the higher volumes of traffic flows. These routes connect most important cities, maritime ports, or production/consumption centers (main origins or destinations) in the region. On the other hand, minor highways connect

small cities with main corridors and with main cities or production/consumption centers.

Figure 4.10 shows the highway links (free and toll highways) created in STAN and used for this study.

Figure 4.10: Highway links (toll and free highways)
(Source: Created in STAN with data from the Mexican Transportation Institute)

4.1.4.2.2 Rail Links

The “phi” coefficient and the beta coefficient can be used for link functions. In this analysis both coefficients for rail links were not used and therefore no value was entered.

The “ul1”, “ul2” and “ul3” attributes were used to store important information used to calculate railroad transportation costs.

Train operating costs were provided by the Chiapas-Mayab Railroad and these costs include diesel and lubricants costs, maintenance labour, rail tracks and equipment maintenance and operator salary. It is important to mention that these costs also include the empty freight cars operating costs that correspond to the empty freight cars moved in a convoy train (50 cars).

Train operating costs depend on terrain type, rail track conditions and the amount of cargo to be carried. For this study, three different costs were provided for three different terrain types and for a standard convoy train of 50 freight cars with an average cargo weight of 3 500 tons/convoy (Refer to Table 4.10).

Table 4.10
Railroad Operating Costs (MXP)

Terrain Type	Code Number	Operating Costs (\$/km)
Level	1	318
Rolling	2	534
Mountainous	3	791

Source: created with information from the Chiapas-Mayab Railroad

Terrain characteristics were obtained from the Chiapas-Mayab Railroad and each terrain type was identified with a different code number and entered interactively for each rail link in attribute "ul2".

Once the terrain type for each rail link was identified the operating costs were entered in attribute "ul1".

To calculate final operating costs it was necessary to identify rail track conditions. Rail track conditions for all rail tracks included in this analysis were provided by the Chiapas-Mayab Railroad and for each condition a different number was assigned. (Refer to Figure 4.11).

Figure 4.11: Rail track conditions

(Source: created in ArcView with information from the Chiapas-Mayab Railroad and the Mexican Transportation Institute)

Rail track conditions and their code number are shown in Table 4.11.

Table 4.11
Rail track conditions

Rail track conditions	Code Number
Good	1
Fair or regular	2
Bad	3

Source: created with information from the Chiapas-Mayab Railroad

It was concluded that all rail tracks located in southeast Mexico selected for this analysis have a fair or regular condition and therefore a value of 2 was selected and entered in attribute "ul3".

Others link attributes were not used for rail links, therefore no values were entered.

Rail links created in STAN are shown in Figure 4.12

Figure 4.13: Rail links

(Source: Created in STAN with data from the Mexican Transportation Institute)

4.1.4.2.3 Connector Links

A connector mode was created to connect centroids (dummy nodes) with the transportation network. According to this, only the function set number "fct" attribute identified before in Table 4.3 was used for connector links.

4.1.5 Transfers

Products sometimes are moved by various modes of transportation to reach their final destination. Transportation facilities such as railroad terminals, multimodal terminals (cross dock and transloading services), intermodal terminals and maritime ports are necessary for transfers.

As mentioned in Chapter 3, in STAN a transfer has the following attributes:

j	transfer node
i	I-node of incoming link, or from-mode
m	mode of incoming link, or from-mode
k	J-node of outgoing link, or to-node
n	mode of outgoing link, or to-mode
fct	transfer function set number, 0=free transfer
phit	transfer phi coefficient
ut1,ut2,ut3	transfer user data

Transfer function set number "fct" was the only attribute for transfers used in this analysis. Function set numbers (fct) is an index number pointing to the set of functions used to determine the cost of moving one unit of product through a transfer. This number will represent the cost of moving the products from one mode of transportation to another mode of transportation.

For this analysis three different types of transfers were created:

1. from connectors to rail or roads,
2. from roads to rail or from rail to roads, and
3. from free roads to toll roads.

According to the information provided by the Chiapas-Mayab Railroad the cost for transfers between railroad and roads is **\$15.00 MXP/ton**. It is important to mention that there is no cost for transfers between toll and free roads.

Function set numbers assigned to each type of transfer are shown in Table 4.12.

Table 4.12
Transfer function set number

Function Set Number/Transfers	
Type of Transfer	Function set number
Connector - all modes	1
Road - Rail	2
Free Roads - Toll Roads	3

Information about terminals that are currently used for transfers between railroad and highways in southeast Mexico was provided by the Chiapas-Mayab Railroad, and information for transfers between toll and free roads was obtained from the Mexican Transportation Institute.

There are 34 transfer points and all transfers were entered interactively in the STAN data bank. Transfers distribution and their characteristics are shown in Table 4.13, Figure 4.13 and Figure 4.14. For transfers detail refer to Appendix F.

Table 4.13
Transfer points distribution

	Transfer No.	Location	Transfer between		
			Railroad	Free roads	Toll roads
1	1710	Puerto Madero (maritime port)	X	X	
2	1714	Tapachula	X	X	
3	1703	Ciudad Hidalgo	X	X	
4	1474	Huixtla		X	X
5	1718	Tonala	X	X	
6	1468	Arriaga	X	X	X
7	1467	Tehuantepec	X	X	
8	1469	Salina Cruz (maritime port)	X	X	
9	1433	Acayucan		X	X
10	1429	Cosoleacaque		X	X
11	1427	Minatitlan	X	X	X
12	1421	Coatzacoalcos	X	X	
13	1423	Nuevo Teapa		X	X
14	3708	Roberto Ayala	X	X	
15	3707	Teapa	X	X	
16	4	Pino Suarez	X	X	
17	1443	Palenque	X	X	
18	3706	Tenosique	X	X	
19	2	Malpaso		X	X
20	1461	Tuxtla Gutierrez		X	X
21	1462	San Cristobal de las Casas		X	X
22	1403	El Zacatal		X	X
23	1394	El Zacatal		X	X
24	1401	Escarcega	X	X	
25	1323	Champoton		X	X
26	1271	Campeche (maritime port)	X	X	X
27	1186	Uman	X	X	
28	1180	Merida	X	X	
29	1156	Puerto Progreso (maritime port)	X	X	
30	1193	Kantunil		X	X

31	1200	Valladolid	X	X	X
32	1171	Tizimin	X	X	
33	1188	El Tintal		X	X
34	1168	Cancun (maritime port)		X	X

Source: Created with data from the Mexican Transportation Institute and the Chiapas-Mayab Railroad

Figure 4.13: Transfers location

(Source: Created in STAN with data from the Mexican Transportation Institute and the Chiapas-Mayab Railroad)

Figure 4.14: Transfers between rail and road in southeast Mexico
 (Source: Created in ArcView with data from the Chiapas-Mayab Railroad)

4.2 Defining Vehicles

In STAN a vehicle has the following attributes:

Product number	number defined to refer to a product
Mode identifier	letter used to identify the modes
wbyveh	product weight by vehicle, the usual load of the vehicle (ton)
vehwgt	vehicle weight (when empty)(ton)
conwght	convoy weight (ton) (maximum number of cars)
uv1, uv2, uv3	three user defined vehicle data (optional)

In this analysis trucks were used as vehicles for the road transportation and freight cars grouped in convoy trains were used for the rail mode. No real vehicles exist for the connector mode; however dummy vehicles were defined for this mode.

According to a study made by the Ministry of Communications and Transports Mexico, the commercial truck flow on the highway network in southeast Mexico is mainly integrated by unitary trucks type C2 and C3 and trailers type T3-S2, T3-S3 and T3-S2-R4. However, this study also shows that the

commercial truck flow on main corridors is mainly integrated by truck trailers type T3-S2 and T3-S3 (Jimenez et al., 2001).

The truck selected for this analysis is the International 9200i truck trailer type T3-S2 (tractor trailer of 40 feet). This truck trailer is the typical vehicle used in Mexico for freight transportation analysis and simulation optimization studies. Technical characteristics for this truck were obtained from the retail dealer web page and are included in Appendix E.

Vehicle attribute values were obtained from the Chiapas-Mayab Railroad and from the Mexican Transportation Institute according to the type of product to be transported. (Refer to Table 4.14)

It is important to mention that according to the Ministry of Communications and Transports the maximum convoy weight authorized (product weight by vehicle + vehicle weight) to circulate on highways is 44 tons. (Refer to Appendix E). This value was verified for the four products and no restrictions were found.

Vehicles attributes were entered interactively in STAN and are shown in Table 4.15.

Table 4.14
Vehicles attributes for each product

	Product identifier	Cement	Combustoleo	Corn	Wood
		p=1	p=2	p=3	p=4
Toll Roads	mode	a	a	a	a
	wbyveh (ton)	23	20	12	13
	vehwgt (ton)	17	17	17	17
	conwgt (ton)	40	37	29	30
	uv1	0	0	0	0
	uv2	0	0	0	0
	uv3	0	0	0	0
Free Roads	mode	c	c	c	c
	wbyveh (ton)	23	20	12	13
	vehwgt (ton)	17	17	17	17
	conwgt (ton)	40	37	29	30
	uv1	0	0	0	0
	uv2	0	0	0	0
	uv3	0	0	0	0
Railway	mode	r	r	r	r
	wbyveh (ton)	72	69	75	65
	vehwgt (ton)	30	30	30	30
	conwgt (ton)	5100	4950	5250	4750
	uv1	0	0	0	0
	uv2	0	0	0	0
	uv3	0	0	0	0
Connector	mode	n	n	n	n
	wbyveh (ton)	1	1	1	1
	vehwgt (ton)	0	0	0	0
	conwgt (ton)	1	1	1	1
	uv1	0	0	0	0
	uv2	0	0	0	0
	uv3	0	0	0	0

Source: Created with data from the Chiapas-Mayab Railroad, Mexican Transportation Institute and Ministry of Communications and Transports Mexico

Table 4.15
STAN Vehicle Table

STAN Module:

2.03

Date:

04-11-02 19:36

User:

S050/CARLETON..CVA

Project:

Freight Transportation in Southeast Mexico

Scenario 1000:

Current situation:optimization

V E H I C L E T A B L E

Product	Mode	Weight per vehicle (t)	Vehicle weight (t)	Convoy weight (t)	-- user defined data --		
					uv1	uv2	uv3
1	a	23.000	17.000	40.000	.000	.000	.000
1	c	23.000	17.000	40.000	.000	.000	.000
1	n	1.000	.000	1.000	.000	.000	.000
1	r	72.000	30.000	5100.000	.000	.000	.000
Product	Mode	Weight per vehicle (t)	Vehicle weight (t)	Convoy weight (t)	-- user defined data --		
					uv1	uv2	uv3
2	a	20.000	17.000	37.000	.000	.000	.000
2	c	20.000	17.000	37.000	.000	.000	.000
2	n	1.000	.000	1.000	.000	.000	.000
2	r	69.000	30.000	4950.000	.000	.000	.000
Product	Mode	Weight per vehicle (t)	Vehicle weight (t)	Convoy weight (t)	-- user defined data --		
					uv1	uv2	uv3
3	a	12.000	17.000	29.000	.000	.000	.000
3	c	12.000	17.000	29.000	.000	.000	.000
3	n	1.000	.000	1.000	.000	.000	.000
3	r	75.000	30.000	5250.000	.000	.000	.000
Product	Mode	Weight per vehicle (t)	Vehicle weight (t)	Convoy weight (t)	-- user defined data --		
					uv1	uv2	uv3
4	a	13.000	17.000	30.000	.000	.000	.000
4	c	13.000	17.000	30.000	.000	.000	.000
4	n	1.000	.000	1.000	.000	.000	.000
4	r	65.000	30.000	4750.000	.000	.000	.000

4.3 Defining Functions

Generalized cost is the most common type of cost considered in STAN. Generalized cost is the sum or combination of three different cost components for all products, links and transfers. These cost components are: operating costs, delay costs and other costs. According to STAN, the user must define the functions that will be used for these components.

It is important to mention that the functions that are used in STAN are unit cost functions, and unit cost functions are the cost of moving one unit of flow over the network (links and/or transfers) (MXP/ton). Unit cost functions are user defined and should have similar measures for all modes (compatible).

During assignment, unit cost functions (MXP/ton) are multiplied by product volumes (ton) on links and transfers for each product.

In parts 4.1.4.2 and 4.1.5 of this chapter function sets were entered for links and transfers respectively. Each function set number has the following three standard attributes:

- A function set component number represented by an integer equal to 1, 2 or 3. Each component number represents the generalized cost component (1=operating cost, 2=delay cost, 3=other cost) to which the product function indexes apply.

- A function set index represented by a number between 1 and the maximum number of link function sets for links, or the maximum number of transfer function sets for transfers. A function set index must be defined for each link.
- Function pointers: a link (transfer) function index for each combination of product and function set component.

4.3.1 Function Set Number

The functions defined for this analysis include link functions and transfer functions that will be used to calculate the transportation costs through the network (transfers and links). Function sets for links and transfers defined for this analysis are shown in Table 4.16 and Table 4.17 respectively.

Table 4.16
Function sets for links

Link Type	Function set number	Function Set Component Number	Function Set Index			
			Function for Product 1	Function for Product 2	Function for Product 3	Function for Product 4
Road links: toll roads	1	1 (Operating costs)	f11	f11	f11	f11
		2 (Delay costs)	f16	f16	f16	f16
		3 (Toll costs)	f112	f112	f112	f112
Road links: free roads	2	1 (Operating costs)	f11	f11	f11	f11
		2 (Delay costs)	f17	f17	f17	f17
		3 (Toll costs)	f112	f112	f112	f112
Rail links: single track	3	1 (Operating costs)	f12	f13	f14	f15
		2 (Delay costs)	f18	f19	f110	f111
		3 (Other costs)	f113	f113	f113	f113
Connector links	4	1 (Operating costs)	f114	f114	f114	f114
		2 (Delay costs)	f114	f114	f114	f114
		3 (Other costs)	f114	f114	f114	f114

Table 4.17
Function sets for transfers

Link Type	Function set number	Function Set Component Number	Function Set Index			
			Function for Product 1	Function for Product 2	Function for Product 3	Function for Product 4
Connector - all modes	1	1 (Operating costs)	ft1	ft1	ft1	ft1
		2 (Delay costs)	ft1	ft1	ft1	ft1
		3 (Other costs)	ft1	ft1	ft1	ft1
Road - Rail	2	1 (Operating costs)	ft2	ft2	ft2	ft2
		2 (Delay costs)	ft1	ft1	ft1	ft1
		3 (Other costs)	ft1	ft1	ft1	ft1
Free Roads - Toll Roads	3	1 (Operating costs)	ft1	ft1	ft1	ft1
		2 (Delay costs)	ft1	ft1	ft1	ft1
		3 (Other costs)	ft1	ft1	ft1	ft1

4.3.2 Function Set Index

Function set index is used to determine the costs (operating, delay and other costs) of moving products through the network (links and transfers). In this analysis fourteen functions set index were defined to calculate costs on links and two functions set index were defined to calculate costs for transfers.

4.3.2.1 Function set index: Road links

Equation 4.2 was created to transform MXP/km units to MXP/ton units. Equations 4.3 and 4.4 were obtained from a study carried out by Valdez et al. (2002) from the Mexican Transportation Institute, based on a research made by Branston D. in 1976 in which a congestion factor is determined based on the AADT on highways. According to Valdez et al. (2002), equation 4.3 can be used for highways with free flow speed of more than 80 km/h, and equation 4.4 can be used for highways with a free flow speed between

66 and 80 km/h. Equation 4.5 was created to transform highway cost toll units to MXP/ton units.

$$f1 = (ul1/wbyveh) * length \quad (4.2)$$

where:

- $f1$ = operating costs (MXP/ton)
- $ul1$ = operating costs (MXP/km)
- $wbyveh$ = product weight by vehicle (ton)
- $length$ = link length (km)

$$f6 = ((ul1/wbyveh) * length) * 1.1491 * (vehtot / ((cap - 1.5 * (ul2 - ul3)) / 5))^{6.8677} \quad (4.3)$$

where:

- $f6$ = toll roads delay cost (MXP/ton)
- $ul1$ = operating costs (MXP/km)
- $wbyveh$ = product weight by vehicle (ton)
- $length$ = link length (km)
- $vehtot$ = vehicle equivalent of total product volume on a link
- cap = link capacity (veh/day)
- $ul2$ = (AADT + 2 (AADT for buses))
- $ul3$ = AADT for freight trucks

Please note that equations 4.3 and 4.4 contain variables, calibration constants and powers. In this research the variables that contain Mexican

pesos take values for year 2003. The calibration constants and powers do not change from year to year.

$$fl7 = ((ul1/wbyveh) * length) * 0.6609 * (vehtot / (cap - 1.5 * (ul2 - ul3))) / 5^{5.0906}$$

(4.4)

where:

- fl7 = free roads delay cost (MXP/ton)
- ul1 = operating costs (MXP/km)
- wbyveh = product weight by vehicle (ton)
- length = link length (km)
- vehtot = vehicle equivalent of total product volume on a link
- cap = link capacity (veh/day)
- ul2 = (AADT + 2 (AADT for buses))
- ul3 = AADT for freight trucks

$$fl12 = ((phil/length)/wbyveh)$$

(4.5)

where:

- fl12 = highway toll costs (MXP/ton) (fl6 = 0, for free roads)
- phil = highway toll costs (MXP)
- length = link length (km)
- wbyveh = product weight by vehicle (ton)

4.3.2.2 Function set index: Rail links

$$f12 = ((length * ul1) / 3600) * ((1 + (ul3 - 1)) / 2) \quad (4.6)$$

where:

- $f12$ = operating costs (cement) (MXP/ton)
- $ul1$ = operating costs (MXP/km) according to the type of terrain
- $ul3$ = rail track conditions (Good=1, Fair=2, Poor=3)

$$f13 = ((length * ul1) / 3450) * ((1 + (ul3 - 1)) / 2) \quad (4.7)$$

where:

- $f13$ = operating costs (combustoleo) (MXP/ton)
- $ul1$ = operating costs (MXP/km) according to the type of terrain
- $ul3$ = rail track conditions (Good=1, Fair=2, Poor=3)

$$f14 = ((length * ul1) / 3750) * ((1 + (ul3 - 1)) / 2) \quad (4.8)$$

where:

- $f14$ = operating costs (corn) (MXP/ton)
- $ul1$ = operating costs (MXP/km) according to the type of terrain
- $ul3$ = rail track conditions (Good=1, Fair=2, Poor=3)

$$f15 = ((length * ul1) / 3250) * ((1 + (ul3 - 1)) / 2) \quad (4.9)$$

where:

- $f15$ = operating costs (wood) (MXP/ton)
- $ul1$ = operating costs (MXP/km) according to the type of terrain

- ul3 = rail track conditions (Good=1, Fair=2, Poor=3)

$$f18 = ((length * ul1) / 3600) * ((1 + (ul3 - 1)) / 2) * (0.019643 * (vehprod / 50) + (4.8119 * (((vehprod / 50) / (0.8 * cap))^6))) \quad (4.10)$$

where:

- fl8 = delay costs (cement) (MXP/ton)
- ul1 = operating costs (MXP/km) according to the type of terrain
- ul3 = rail track conditions (Good=1, Fair=2, Poor=3)
- vehprod = vehicle equivalent of current product volume on link.
(volprod/wbyveh) (calculated by STAN)
- cap = link capacity (number of trains per day)

$$f19 = ((length * ul1) / 3450) * ((1 + (ul3 - 1)) / 2) * (0.019643 * (vehprod / 50) + (4.8119 * (((vehprod / 50) / (0.8 * cap))^6))) \quad (4.11)$$

where:

- fl9 = delay costs (combustoleo) (MXP/ton)
- ul1 = operating costs (MXP/km) according to the type of terrain
- ul3 = rail track conditions (Good=1, Fair=2, Poor=3)
- vehprod = vehicle equivalent of current product volume on link.
(volprod/wbyveh) (calculated by STAN)
- cap = link capacity (number of trains per day)

$$f_{10} = ((\text{length} * u_1) / 3750) * ((1 + (u_3 - 1)) / 2) * (0.019643 * (\text{vehprod} / 50) + (4.8119 * (((\text{vehprod} / 50) / (0.8 * \text{cap}))^6))) \quad (4.12)$$

where:

- f_{10} = delay costs (corn) (MXP/ton)
- u_1 = operating costs (MXP/km) according to the type of terrain
- u_3 = rail track conditions (Good=1, Fair=2, Poor=3)
- vehprod = vehicle equivalent of current product volume on link.
($\text{volprod} / \text{wbyveh}$) (calculated by STAN)
- cap = link capacity (number of trains per day)

$$f_{11} = ((\text{length} * u_1) / 3250) * ((1 + (u_3 - 1)) / 2) * (0.019643 * (\text{vehprod} / 50) + (4.8119 * (((\text{vehprod} / 50) / (0.8 * \text{cap}))^6))) \quad (4.13)$$

where:

- f_{11} = delay costs (wood) (MXP/ton)
- u_1 = operating costs (MXP/km) according to the type of terrain
- u_3 = rail track conditions (Good=1, Fair=2, Poor=3)
- vehprod = vehicle equivalent of current product volume on link.
($\text{volprod} / \text{wbyveh}$) (calculated by STAN)
- cap = link capacity (number of trains per day)

$$f_{l13} = 0 \quad (4.14)$$

where:

- f_{l13} = other costs (not used in this mode)

Equations from 4.6 to 4.13 are used to calculate operating and delay costs and were obtained from a study made by Centeno et al., (2003). Delay costs are calculated based on a congestion factor that is later multiplied by the operating costs.

4.3.2.3 Functions set index: Connector links

$$f_{l14}=0 \quad (4.15)$$

where:

- f_{l14} = other costs (there are no costs for dummy modes)

4.3.2.4 Functions set index: Transfers

$$f_{t1}= 0 \quad (4.16)$$

where:

- f_{t1} = transfer costs between connectors and all modes (MXP/ton)

ft2=\$15.00 MXP/ton

(4.17)

where:

- ft2 = transfer costs between railroad and trucks (MXP/ton)

All function set index for links and transfers were entered in STAN interactively and are shown in Table 4.18 and Table 4.19 respectively.

Table 4.18
Function set table on links

STAN Module:		2.04		Date: 04-11-01 12:36				User: S050/CARLETON..CVA					
Project:		STAN		/project title									
Scenario 1000:		STAN Network from GIS											

F U N C T I O N S E T T A B L E O N L I N K S													

Set/C	Prd Fct		Prd Fct		Prd Fct		Prd Fct		Prd Fct		Prd Fct		
----	---		---		---		---		---		---		
11	1	001	2	001	3	001	4	001					
12	1	006	2	006	3	006	4	006					
13	1	012	2	012	3	012	4	012					
21	1	001	2	001	3	001	4	001					
22	1	007	2	007	3	007	4	007					
23	1	012	2	012	3	012	4	012					
31	1	002	2	003	3	004	4	005					
32	1	008	2	009	3	010	4	011					
33	1	013	2	013	3	013	4	013					
41	1	014	2	014	3	014	4	014					
42	1	014	2	014	3	014	4	014					
43	1	014	2	014	3	014	4	014					

Table 4.19
Function set table on transfers

STAN Module:	2.04	Date:	04-11-01 12:45	User:	S050/CARLETON..CVA			
Project:	STAN	/project title						
Scenario 1000:	STAN Network from GIS							

F U N C T I O N S E T T A B L E O N T R A N S F E R S								

Set/C	Prd	Fct	Prd	Fct	Prd	Fct	Prd	Fct
----	---	---	---	---	---	---	---	---
11	1	001	2	001	3	001	4	001
12	1	001	2	001	3	001	4	001
13	1	001	2	001	3	001	4	001
21	1	002	2	002	3	002	4	002
22	1	001	2	001	3	001	4	001
23	1	001	2	001	3	001	4	001
31	1	001	2	001	3	001	4	001
32	1	001	2	001	3	001	4	001
33	1	001	2	001	3	001	4	001

In the first column (Set/C), the function set index and component number are listed as one number. For example, the number 11 refers to the function set 1, component 1. The next two columns list the product number (Prd) and the function pointer (Fct) for each function set component. These two columns are repeated for each product.

4.4 Origin – Destination Matrices

Origin-destination pairs and product volume for each product were determined before in Chapter 2. These matrices were created with information provided by the Mexican Transportation Institute and from the Chiapas-Mayab Railroad (Refer to Figure 4.15).

	No	Origin	No	Destination	Railroad		Truck		Total
					Distance (km)	Vol (ton/wk)	Distance (km)	Vol (ton/wk)	
Cement (1)	10	Connecting	40	Arriaga	311	3,072	343	9,800	12,872
	10	Connecting	30	Merida	895	413	782	10,983	11,396
	10	Connecting	50	Cd. Hidalgo	617	3,200	583	14,469	17,669
	10	Connecting	60	R. Ayala	128	3,861	224	15,939	19,800
	20	Pino Suarez	50	Cd. Hidalgo	0	0	529	1,075	1,075
	30	Pino Suarez	30	Merida	605	4,384	504	8,253	12,637
	30	Merida	70	Puerto Juarez (Cancun)	0	0	318	13,790	13,790
						14,930		74,309	89,239
	No	Origin	No	Destination	Railroad		Truck		Total
					Distance (km)	Vol (ton/wk)	Distance (km)	Vol (ton/wk)	
Combustoleo (2)	80	Campeche	30	Merida	173	829	180	0	829
	80	Campeche	100	Valladolid	332	293	337	0	293
	90	Coatzacoalcos	30	Merida	888	5501	716	0	5501
	90	Coatzacoalcos	100	Valladolid	1047	2201	876	0	2201
	90	Coatzacoalcos	70	Puerto Juarez	0	0	1037	20314	20314
						8824		20314	29138
	No	Origin	No	Destination	Railroad		Truck		Total
					Distance (km)	Vol (ton/wk)	Distance (km)	Vol (ton/wk)	
Corn (3)	110	Salina Cruz	30	Merida	1159	1,022	1,049	3,815	4,837
	110	Salina Cruz	40	Arriaga	201	618	192	1,908	2,526
	120	Progreso	30	Merida	0	0	33	11,137	11,137
						1,640		16,860	18,500
	No	Origin	No	Destination	Railroad		Truck		Total
					Distance (km)	Vol (ton/wk)	Distance (km)	Vol (ton/wk)	
Wood (4)	60	Roberto Ayala	10	Connecting	128	1,363	224	3,370	4,733
						1,363		3,370	4,733

Figure 4.15: Origin – Destination Matrices

Origin-destination matrices were created in STAN (Refer to Figure 4.16) for each of the four selected products (Cement, Combustoleo, Corn and Wood) and identified with a different code:

- Cement= mf1
- Combustoleo= mf2
- Corn= mf3
- Wood= mf4

STAN Module:	3.12	Date:	04-11-02 13:47	User:	S050/CARLETON..CVA
Project:	Freight Transportation in Southeast Mexico				

Matrix Directory					

Matrix:	Flags:	Modified:	Description:		
mf01: Cement		04-11-02 13:07	Cement transportation (tons/wk)		
mf02: Combust		04-11-02 13:30	Combustoleo transpt. (tons/wk)		
mf03: Corn		04-11-02 13:37	Corn transportation (tons/wk)		
mf04: Wood		04-11-02 13:40	Wood transportation (tons/wk)		

Figure 4.16: STAN Origin-Destination Matrices

It is important to mention that according to STAN all product volumes need to be entered in STAN in tons per week.

Matrices created in STAN for each product are shown below and contains the products volume (tons/wk) moved from origin to destination. Values in the first column represent origin centroids and values in first row represent destination centroids.

STAN Module: 3.14 Date: 04-11-02 14:07 User: S050/CARLETON..CVA

Project: Freight Transportation in Southeast Mexico

Matrix mf01: Cement Cement transportation (tons/wk)

Matrix mf01: Cement (Cement transportation (tons/wk))

	destination zones										
	10	20	30	40	50	60	70	80	90	100	
origin zones											
10	0	0	11396	12872	17669	19800	0	0	0	0	
20	0	0	12637	0	1075	0	0	0	0	0	
30	0	0	0	0	0	0	13790	0	0	0	
40	0	0	0	0	0	0	0	0	0	0	
50	0	0	0	0	0	0	0	0	0	0	
60	0	0	0	0	0	0	0	0	0	0	
70	0	0	0	0	0	0	0	0	0	0	
80	0	0	0	0	0	0	0	0	0	0	
90	0	0	0	0	0	0	0	0	0	0	
100	0	0	0	0	0	0	0	0	0	0	
110	0	0	0	0	0	0	0	0	0	0	
120	0	0	0	0	0	0	0	0	0	0	
sum	0	0	24033	12872	18744	19800	13790	0	0	0	

Figure 4.17: Cement O-D matrix

STAN Module: 3.14 Date: 04-11-02 14:14 User: S050/CARLETON..CVA
Project: Freight Transportation in Southeast Mexico
Matrix mf02: Combust Combustoleo transpt. (tons/wk)

Matrix mf02: Combust (Combustoleo transpt. (tons/wk))

	destination zones										
	10	20	30	40	50	60	70	80	90	100	
origin zones											
10	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0
80	0	0	829	0	0	0	0	0	0	0	293
90	0	0	5501	0	0	0	20314	0	0	0	2201
100	0	0	0	0	0	0	0	0	0	0	0
110	0	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0	0
sum	0	0	6330	0	0	0	20314	0	0	0	2494

Figure 4.18: Combustoleo O-D matrix

STAN Module: 3.14 Date: 05-01-12 15:33 User: S050/CARLETON..CVA
 Project: Freight Transportation in Southeast Mexico
 Matrix mf03: Corn Corn transportation (tons/wk)

Matrix mf03: Corn (Corn transportation (tons/wk))

origin zones	destination zones 10	20	30	40	50	60	70	80	90	100
10	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0
110	0	0	4837	2526	0	0	0	0	0	0
120	0	0	11137	0	0	0	0	0	0	0
sum	0	0	15974	2526	0	0	0	0	0	0

Figure 4.19: Corn O-D matrix

STAN Module: 3.14 Date: 04-11-02 14:17 User: S050/CARLETON..CVA
 Project: Freight Transportation in Southeast Mexico
 Matrix mf04: Wood Wood transportation (tons/wk)

Matrix mf04: Wood (Wood transportation (tons/wk))

origin zones	destination zones 10	20	30	40	50	60	70	80	90	100
10	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0
60	4733	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0
110	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0
sum	4733	0	0	0	0	0	0	0	0	0

Figure 4.20: Wood O-D matrix

CHAPTER 5 SCENARIOS AND RESULTS

5.1 Preparing scenario for assignment

In STAN, assignment of freight to the multimodal network represents the dual function of simulation and optimization. "For each product and demand matrix, one or several multimodal paths are chosen for the demand between each origin-destination (O-D) pair such as to minimize the total generalized cost of the transportation system" (INRO Consultants Inc., 2002).

Before running the assignment other parameters and criteria were defined:

- All products were included in the assignment (Cement, Combustoleo, Corn, and Wood).
- All modes of transportation were included (toll roads, free roads, railways, connectors).
- All products can be transported by all modes of transportation.
- The stopping criteria were: maximum of 10 iterations or a relative gap of 0.05% (Recommended for small networks) (INRO Consultants Inc., 2002).
- A detailed report was required at the end of the assignment (this calculates the value of each cost component of the generalized cost function at the end of the last iteration of the assignment).

Figure 5.1 shows a summary of assignment parameters.

Figure 5.1: Summary of assignment parameters

The assignment procedure consists of the following steps:

1. Initialization or iteration 0: all volumes are placed on the least costly path. This is similar to "all-or-nothing" assignment in passenger travel networks by using "free flows" travel times.
2. Each subsequent iteration: for each product (with other product volumes fixed):

- Compute the product link and transfer marginal costs with current volumes
 - Compute new shortest marginal cost paths
 - Compute the proportion of demand to move onto new paths
 - Update product flows on links and transfers.
3. The stopping criteria may be a maximum number of iterations or a certain tolerance on the relative gap. The relative gap is an estimation of the difference between the current assignment and an optimal assignment.

When the scenario is ready for the assignment, STAN confirms all the data and parameters that will be considered in the assignment. (Refer to Figure 5.2).

```

STAN Module:      5.21      Date: 04-11-02 15:44      User: S050/CARLETON..CVA
Project:          Freight Transportation in Southeast Mexico
-----
Scenario:         1000: Current situation:optimization
Network size:     4 modes           4 products
                  12 centroids      80 regular nodes
                  273 links         282 transfers
Mincost assignment: 04-11-02 15:32 (prepared, not assigned)
Product          Demand  Modes
Cement           mf01    acnr
Combustoleo      mf02    acnr
Corn             mf03    acnr
Wood             mf04    acnr
Generalized cost:  1*(operating cost) + 1*(delay cost) + 1*(other cost)
Stopping criteria: maximum number of iteration(s)= 10      gap= 0.05%

```

Figure 5.2: STAN parameters confirmation

Once the scenario is ready for the assignment, the next step in the process is to run the assignment.

5.2 Analysis of Results

While running the assignment it was found that 10 interactions were not sufficient to get the relative gap value assigned for the stopping criteria, therefore new iterations were performed and after 35 interactions it was found that the relative gap value was 1.05% which was considered acceptable. (Refer to Figure 5.3)

```

STAN Module:      6.01      Date: 04-11-04 16:07      User: S050/CARLETON..CVA
Project:          Freight Transportation in Southeast Mexico
Scenario 1000:    Current situation: optimization
-----
HINCOST ASSIGNMENT
*****

Scen. 1000 - Network size:      12 centroids
                                80 regular nodes
                                274 active links
                                392 active transfers

Modes:      a Toll Roads      c Free roads      n Connector
            r Railway

Hincost assignment:  04-11-03 23:38
Product            Demand      Modes
Cement             mf01        acnr
Combustoleo        mf02        acnr
Corn               mf03        acnr
Wood               mf04        acnr

Generalized cost:    1*(operating cost) +      1*(delay cost) +      1*(other cost)
Stopping criteria:   maximum number of iteration(s)= 35      gap= 0.05%

Results:
Current iteration:   35
Objective function value: 0.228206E+08
Best lower bound:    0.225812E+08
Gap:                 1.05 %

Cost component values: Operating cost value: 0.206391E+08
                      Delay cost value:    0.185898E+07
                      Other cost value:     0.322538E+06

Number of iterations: 35      stopped by: iter

```

Figure 5.3: STAN Assignment Summary

It is important to remember that the main purpose of this research is to optimize the current situation of freight transportation in southeast Mexico from a social point of view. The results generated by STAN for all products were analyzed and compared with the current situation.

The results and findings of the analysis are the following:

1. The optimization shows that 39 percent of the total cargo moved in the network was assigned to road transportation and 61 percent was assigned to railroad transportation. At present times the total cargo is transported with the following distribution: 81 percent by road transportation and 19 percent by rail transportation. (Refer to Figure 5.4)

Figure 5.4: Freight distribution in southeast Mexico

The diagnosis is that the transportation of the four products can be considerably improved and important savings and reductions can be obtained in transportation costs, pollution to the environment and diesel fuel consumption.

2. The optimization results show that 71 percent of cement volume was assigned to railroad and 29 percent was assigned to road transportation. Currently, 83 percent of the total cement freight is transported by trucks and only 17 percent is moved by railroad. This means that at present times all cement cargo is not well distributed and that transportation costs could be considerably reduced. (Refer to Figure 5.5 and Figure 5.6).

Figure 5.5: Cement distribution in southeast Mexico

Figure 5.6: Optimal cement distribution

3. The results of the analysis show that the combustoleo volume was assigned with the following distribution: 38 percent to railroads and 62 percent to road transportation. These numbers are similar to current situation where 30 percent of all combustoleo cargo is transported by railroads and 70 percent is moved by road transportation. It can be said that at present times this product is well distributed and probably transportation costs for both situations will be similar. (Refer to Figure 5.7 and Figure 5.8)

Figure 5.7: Combustoleo distribution in southeast Mexico

Figure 5.8: Optimal combustoleo distribution

The fact that both optimal and current combustoleo transportation are similar could be because one of the destinations (Puerto Juarez) is not connected by railroad and the combustoleo volume with origin Coatzacoalcos is moved in part by railroad to Valladolid where all the combustoleo cargo is transferred to trucks to be delivered in Puerto Juarez.

4. The optimization shows that 100 percent of the corn volume is transported by railroad. At present times the numbers are totally different, 9 percent of the total cargo is carried by railroad transportation and 91 percent is carried by road transportation. The diagnosis is that corn cargo is not well distributed and advantages of railroad transportation are not considered. This difference could be representing important savings of transportation costs. (Refer to Figure 5.9 and Figure 5.10)

Figure 5.9: Corn distribution in southeast Mexico

Figure 5.10: Optimal corn distribution

It can also be observed that 60 percent of the total corn cargo is moved from the Port of Progreso to the city of Merida. All this cargo is assigned to railroad transportation because this highway route is overused and rail condition and capacity connecting these points are very good. In fact, this rail route has one the largest capacity in the network.

5. The optimization shows that 100 percent of the wood cargo must be transported by railroad transportation. At present times 29 percent of the total cargo is moved by railroad and 71 percent is transported by road transportation. It can be observed that the highways connecting the origin

with the destination are overused where railways have a large capacity.
(Refer to Figure 5.11 and Figure 5.12).

Figure 5.11: Wood distribution in southeast Mexico

Figure 5.12: Optimal wood distribution

6. Optimal unit transportation costs for all products and for each mode of transportation are shown in the following table:

Table 5.1
Transportation unit costs

	Cement	Combustoleo	Corn	Wood
	(MXP/ton)			
Toll roads	18	17.1	X	X
Free roads	29	33.24	X	X
Railroad	11.58	12.65	8.26	5.35

It can be observed that unit costs for free roads are greater than for toll roads. Toll roads are scarce in the region and most of the cargo for road transportation was assigned to free roads which have inferior characteristics (pavement surface conditions, geometric design and capacity) and are more congested than toll roads (Refer to Appendix G). The consequence of this situation is an increase of traffic and an increment of delay costs on free roads giving as a result higher transportation costs and higher unit costs.

Transportation costs for the current and optimal situation and transportation savings for each product are presented in the following table:

Table 5.2
Transportation costs savings

Product	Modes of transportation	Optimization		Current Situation		Savings (MXP)
		Volume (t)	Costs (MXP)	Volume (t)	Costs (MXP)	
Cement	Roads	25,879.00	608,157.00	74,309.00	1,746,261.50	30.00%
	Railroads	63,360.00	733,708.00	14,930.00	172,889.40	
	Total	89,239.00	1,341,865.00	89,239.00	1,919,150.90	
Combustoleo	Roads	18,066.00	454,721.22	20,314.00	511,303.38	4.50%
	Railroads	11,072.00	140,060.80	8,824.00	111,623.60	
	Total	29,138.00	594,782.02	29,138.00	622,926.98	
Corn	Roads	0.00	0.00	16,860.00	295,893.00	51.00%
	Railroads	18,500.00	152,810.00	1,640.00	13,546.40	
	Total	18,500.00	152,810.00	18,500.00	309,439.40	
Wood	Roads	0.00	0.00	3,370.00	59,143.50	62.00%
	Railroads	4,733.00	25,132.23	1,363.00	7,237.53	
	Total	4,733.00	25,132.23	4,733.00	66,381.03	

From the above table the following observations can be made:

- the optimization can reduce transportation costs by up to 62 percent for some products.
- important savings can be obtained by changing the mode of transportation for wood and corn products, and
- no changes are required for combustoleo transportation and some changes are required in order to improve cement transportation.

7. It is important to mention that additional reduction in railroad transportation costs could be obtained if rail track condition is improved. (Refer to part 4.3.2.2 of this chapter).

8. Main transportation corridors in the region were identified and are shown in Figure 5.13. These corridors are similar to those identified by the ministry of communications and transport in Mexico, and by the Mexican Transportation Institute (Refer to Figure 2.3).

Figure 5.13: Transportation corridors

According to the above figure, three corridors are identified in the region:

- the first corridor starts in Puerto Juarez at the extreme northeast of the Yucatan Peninsula then connects with Merida at the northwest of the Yucatan Peninsula, and ends in the Port of Coatzacoalcos.
- the second corridor goes from Ciudad Hidalgo to the Port of Salina Cruz, and

- the third corridor connects the Port of Salina Cruz with the Port of Coatzacoalcas. This corridor is known as the "Transistmico corridor" and is considered a strategic corridor because it connects the Gulf of Mexico with the Pacific Ocean.

Rail tracks in corridor one have some parts with reduced capacity that can be considered bottlenecks. At these points, cargo transported by railroad is transferred to trucks to be transported until a point where rail capacity is higher (transportation costs are reduced) where cargo is then transferred back to railroads. This situation is particularly occurring in the route Pino Suarez – Tenosique – Escarcega, and in the route Campeche – Merida. (Refer to Figure 5.14).

Figure 5.14: Rail tracks capacity problems

This situation is more evident for cement transportation where almost 60 percent of its total volume is transported in corridor one from near of Coatzacoalcos to Merida. Cargo transported in this route is transferred to road transportation in Roberto Ayala due to reduced rail track capacity that increases railroad transportation costs.

9. Transfer costs are important because they can affect total transportation costs. The optimization results show that transfer costs represent almost six percent of total transportation costs. From the results can be observed that transfers points are used for two reasons:

- to reach final destination where railroad infrastructure has no access (multimodal transportation), or
- when transportation costs due to rail or road capacity are higher than for the use of other mode of transportation.

10. In general, cargo distribution can be considerably improved in order to gain important benefits. To better understand the optimal distribution given by STAN, the following figures can be compared. The first figure shows the AADT for highways, the second one shows the highway capacity and the third one shows the rail capacity. It is important to remember that delay costs are calculated considering capacity and current traffic on highways and railways.

- This figure shows the rail capacity (trains/day).

Figure 5.17: Rail capacity in southeast Mexico

Comparing the figures shown above, it can be observed that points (origins and/or destinations) connected by highways with a higher AADT and a medium or low capacity are the same points connected by railroad with large capacity. This means that some of the cargo moved in these zones was assigned to the railroad in order to avoid extra costs on highways (delay costs on congested highways).

This situation is more evident for wood cargo that was completely assigned to the railroad from its origin to its destination where rail

capacity is larger and where highway traffic volumes are higher compared with a low-medium highway capacity.

Graphics and other results generated by STAN are included in Appendix H:

- Results by mode
- Results by link type
- Volume distribution by mode of transportation.
- Volume distribution for type of product.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. STAN is a good tool for freight simulation - optimization; it is flexible, offers a variety of functions to calibrate the model and the results are precise. However, using STAN is somewhat complicated and some times other information, functions and characteristics are not well explained. STAN environment is not user friendly and its manipulation is sometimes tedious and difficult.
2. It can be concluded that freight transportation in southeast Mexico is not well distributed and important changes can be made. Only combustoleo is well distributed and all other three products need to be redistributed or optimized in order to reduce transportations costs, road maintenance, damage to the roads by heavy trucks, air pollution and diesel fuel consumption.
3. The optimization implies a redistribution of the cargo moved in the region according to the results obtained.
4. It can be observed that rail capacity is not uniform in all routes. This situation is causing delay costs and transfer costs giving as a result an increase in total transportation costs.

5. The railroad in southeast Mexico is currently moving cargo at the average level of 55,000 tons/wk. The optimization shows that total cargo of 86,000 tons/wk could be assigned to the railroad, which means that cargo on railroads could be increased by 56 percent if tractive force will be guaranteed.
6. It can be concluded that at present time, in southeast Mexico, the mode choice does not greatly depend on transportation costs. Other factors as travel time and bad railroad service reputation could be affecting the mode choice criteria even when the railroad is a cheaper mode of transportation.
7. The optimal transportation distribution and its savings could vary if some particular product requirement such as travel time is specified by shippers or customers.
8. It can be concluded that highways are still preferred as a mode of transportation even with congested conditions in routes where railroad has large capacity and lower transportation costs.
9. Observations as part of the analysis suggest that important highways located in main corridors are overused and congested.

10. Railroads in Mexico were privatized approximately seven years ago with the main idea to improve their service and increase the freight transported by this mode of transportation. The diagnostic after seven years could be that even when the railroad service has been improved and important infrastructure and technological investments have been made, the railroad service is not yet perceived as a competitive mode of transportation by non users.
11. It can be concluded that in Southeast Mexico railroad and road transportation are not working together in order to offer better services, reduce transportation costs, reduce pollution to the environment and reduce diesel fuel consumption. In other words, both modes are not working together in order to offer a rail - truck intermodal service.
12. The best performance for freight transportation in southeast Mexico will be achieved when balanced cargo volume is assigned to each mode of transportation, based on their capacities, traffic conditions, transportation costs and origins-destinations. To achieve this, greater volume of freight should be assigned to railroad and the use of road transportation should be restricted for connections between railroad and final destination and for small product volumes. This balanced situation could be affected by other factors like travel times and other specific requirements; however, customers need to realize the

advantages of railroad transportation and that sometimes large travel times can be conveniently used to avoid warehousing costs.

13. It can be concluded that for highway users, shippers and logistic providers, the use of an alternative mode of transportation such as railroad transportation, is not yet a generally accepted measure in order to solve the mobility problems.

6.2 Recommendations

1. On the basis of this research it is suggested that the use of the railroad service should be promoted. Also, this industry should be supported with appropriate policies and regulations that will allow it to have a "temporary" advantage over the truck transportation.
2. On the basis of this research it is suggested that both truck and railroad companies in Mexico start working together to offer complete transportation services by using the advantages of each mode of transportation. This new service or "alliance" will not affect the road transportation industry because most of the times the railroad needs the truck transportation to deliver products from terminals to final customers. In fact, this "alliance" will help make a more rational use of truck fleets and reduce investments for new trucks.

This alliance will also help:

- reduce the truck fleet and all the related costs, and use trucks only to deliver products to places where the railroad has no access or to complete door to door services,
- increase traffic on rail tracks and reduce traffic on highways,
- better plan future expansions and investments in transportation infrastructure and,
- reduce transportation costs.

3. In order to achieve the benefits mentioned in point two (above) it is necessary to have more intermodal and multimodal terminals. On the basis of this research it is suggested to continue with investments in these facilities.
4. The railroad transportation in southeast Mexico is not yet operating at overall capacity level. Currently there are no tractive force problems; however, this capacity could be only reached if its tractive force is increased. On the basis of this research it is suggested to gradually increase the number of locomotives in order to amplify the tractive force and enlarge the freight flow on tracks.
5. Rail track capacity in corridor two is sufficient. On the other hand, on the basis of this research it is suggested to expand rail tracks capacity in corridor three in order to have the same capacity as in corridor two and avoid transfer costs and delay costs that will increase total transportation costs.
6. Highways in corridor two and three are mainly two lane type. On the basis of this research it is suggested to expand their capacity in order to handle future freight flows with origins and destinations in North Mexico and in Central and South America.

7. Information and data about freight transportation in Mexico is sometimes difficult to obtain or sometimes is not complete or updated. On the basis of this research it is suggested to make more surveys and field work in order to have more precise data about freight flows on highways. Without this information it is difficult to perform optimization studies, identify transportation infrastructure problems, and therefore, it will be impossible to know where and when infrastructure improvements should be made.
8. Similar analysis for other regions of the country should be carried out in order to have a complete picture of freight transportation in all Mexico.
9. It is recommended to increase the use of intermodal and rail transportation. To achieve this, it is necessary to provide appropriate information, support and advice in an objective and independent way.

References

Airports and Auxiliary Services (ASA), "National Airport Network". México, 2004 (<http://www.asa.gob.mx>)

ALADI (Latin American Integration Association) web page
<http://www.aladi.org/nsfweb/redisenioSitio/index.htm>, 2004

Altamirano, F., President of the National Association of Private Transportation Mexico (ANTP) (in Spanish). Transporte Siglo XXI Magazine, Mexico 2001.

Altamirano F., President of the National Association of Private Transportation Mexico (ANTP). Transporte Siglo XXI, Mexico, Junio 2004 (<http://www.transportesxxi.com/>)

Anaya, R., Ramírez, R., Mendoza, D., "Multiproduct Flow Freight Modelation for Highways and Railroads in Mexico" (in Spanish). Technical Publication No. 126. Mexican Transportation Institute. Queretaro, México 1999.

Aramburuzabala, M., Vicepresident Grupo Modelo, The Economist Journal,(<http://www.economista.com.mx/>) México, 2004

Arroyo, J. A., Aguerrebere R., "Surface Conditions and Operating Costs in Highways" (in Spanish). Technical Publication No. 202. Mexican Transportation Institute. Queretaro, Mexico 2002.

Atkinson, W., Plants Sites and Parks Magazine, 2003

Bennett, C. R. and Paterson, William D. O., Documentation of HDM-4, Version 1.0, International Study of Highway Development and Management Tools (ISOHDM), United Kingdom, 2000.

Boeing "World Air cargo Forecast" 2002 – 2003

(<http://www.boeing.com/flash.html>)

Bontekoning, C. Macharis, J.J. Trip, "Is a new applied transportation research field emerging? – A review of intermodal rail-truck freight transport literature" Delft University of Technology, The Netherlands, Vrije Universiteit Brussel, Belgium, Elsevier Ltd., 2003.

Brander, R., Wilson, F., "Regional Intermodal Freight Transport Flows and Projections" Transportation Research Record 1763, TRB, National Research Council, Washington, D. C., 2001.

Brooks, M., "North American Free Trade Agreement and Transportation" Transportation Research Record 1763, TRB, National Research Council, Washington, D. C., 2001.

Bureau Transportation Statistics, US Department of Transportation
(http://www.bts.gov/publications/national_transportation_statistics/2003/html/table_01_53.html)

Canadian National Railway web page
http://www.cn.ca/productsservices/supplychain/en_KFSCLTechnology.shtml, 2004

Centeno, A., Mendoza, A., "Multiproduct Intermodal Assignment Model for Truck and Railroad Operations" (in Spanish). Technical Publication No. 222. Mexican Transportation Institute. Queretaro, Mexico, 2003.

Center for Business Information and Documentation in Iberoamerica
"Activities of services sector: Terrestrial Transportation".
<http://www.cidiber.com/infopaises/Mexico/Mexico-06-04.html> México
2002.

Corso, O., Director of Multimodal and Railroad Transportation Tariffs, Ministry of Communications and Transports, Transporte Siglo XXI magazine, México 2004. (<http://www.transportesxxi.com/index.php>)

Crainic, T., Florian, M., Larin, D., "STAN: New Developments" INRO Consultants, Inc., Montreal, Canada, 1993

El Economista, (The Economist journal) <http://www.economista.com.mx/> Mexico, 2004

El Universal Newspaper online (<http://www.el-universal.com.mx/noticiash.html>), July 2004, México.

Enríquez, D., "Coastal Traffic Considerations for the Navigation Law Initiative and Maritime Commerce" (in Spanish). Goodrich Riquelme y Asociados. México, 2002. (<http://www.goodrichriquelme.com/>).

Europe Union, "Activities of the European Union Transport" (http://europa.eu.int/pol/trans/overview_en.htm), 2004

Federal Highways and Bridges, Mexico (CAPUFE). Basic Information Section, Cuernavaca, Mor., Mexico, 2002 (<http://www.capufe.gob.mx>)

Federal Railroad Administration, U.S. Department of Transportation (<http://www.fra.dot.gov/us/content/784>), 2004

Free Trade Area of the Americas (FTAA). (http://www.ftaa-alca.org/alca_s.asp), 2004

Genesee Wyoming Railroad web page

(<http://www.gwrr.com/default.cfm>), 2004

Global Competition Report 2000-2001, World Economic Forum, 2004

Guadalupe, M., Herrera, A., Bustos, A., Aguerrebere, R., "Multimodal and intermodal Terminals in Mexico 2001-2002: Present and Future" (in Spanish). Technical Publication No. 221. Mexican Transportation Institute. Queretaro, Mexico, 2003.

Guélat, J., Florian, M., Crainic, T., "A Multimode Multiproduct Network Assignment Model for Strategic Planning of Freight Flows" Transportation Science Vol. 24 No. 1, Linthicum, MD, U.S.A, 1990.

Gutierrez, H., Mendoza, A., "Statistic Study for Truck Transportation in Mexico: 2002" (in Spanish). Technical Publication No. 31. Mexican Transportation Institute. Queretaro, Mexico, 2003.

Gutierrez, H., Mendoza, A., "Statistic Study for Truck Transportation in Mexico: 2001" (in Spanish). Technical Publication No. 28. Mexican Transportation Institute. Queretaro, Mexico, 2002.

Harwood, D., May, A., Anderson, I., Leiman, L., Archilla, R., "Capacity and Quality of Service of Two-Lane Highways" Midwest Research Institute, University of California Berkeley, 1999.

Harker, P., "Predicting Intercity Freight Flows"; VNU Science Press, Utrecht, The Netherlands, 1987.

Hay, W., "An introduction to transportation engineering". New York Wiley, 1961.

Heredia, F., "Restructuring the Air Freight Transportation in Mexico 1987 - 1996" (in Spanish). Technical Publication No. 123. Mexican Transportation Institute. Queretaro, México, 1999.

Holmgren, J., "Efficient Updating Shortest Path Calculations for Traffic Assignment" Division of Optimization, Department of Mathematics, Linköping Institute of Technology, Linköping, 2004.

INRO Consultants Inc. "Getting Started With STAN: A Beginner's Guide", Montreal, Canada 2002

"Integrated Solutions for Intermodal Transport between the European Union and the Central- and East European Countries", Intermoda, Transport Logistic, Munchen, 2003.

International Civil Aviation Organization Bulletin, 1986

Jimenez, S., Islas, V., Hernandez, S., Perez, J., "Regional Transportation in Southeast Mexico" (in Spanish). Technical Publication No. 174. Mexican Transportation Institute. Queretaro, Mexico, 2001.

Lecona, Jorge, Vicepresident of National Association of Maritime Ports, Mexico (ANTMP) (in Spanish). Transporte Siglo XXI Magazine, Mexico 2003.

Loureiro, C., Ralston, B., "Investment Selection Model for Multicommodity Multimodal Transportation Networks" Transportation Research Record 1522, TRB, National Research Council, Washington, D. C., 1996.

Martner, C., Perez, J., Herrera, A., "General Diagnostic of Logistics Plataform for Freight Transportation in Mexico" (in Spanish). Technical Publication No. 233. Mexican Transportation Institute. Queretaro, Mexico, 2003.

Martner, C., Moreno, A., "Modal Integration in the Port of Veracruz" (in Spanish). Technical Publication No. 150. Mexican Transportation Institute. Queretaro, México, 2000.

McCray P. John, "North American Free Trade Agreement Truck Highway Corridors" Transportation Research Record 1613, TRB, National Research Council, Washington, D. C., 1998.

Mercosur Web page, (<http://www.mercosur.org.uy/pagina1esp.htm>), 2004

Mexican Transportation Institute "Transportation Statistics Manual 2001" (<http://www.imt.mx/cgi-bin/met/met2001/met.pl?b=731s8000&b=ferrocarril>). Queretaro, Mexico, 2002

Mexican Transportation Institute "Transportation Statistics Manual 2002", Queretaro, Mexico 2003.

Mexican Competitiveness Institute, IMCO "Competitiveness Analysis in México" (in Spanish). El Economista journal. México, 2004.

Mexico City Airport Group web page
<http://www.aicm.com.mx/Principal/LíneasAereas/Nacionales/Nacionales.htm>)

Meyer, J. and Straszheim, M., "Techniques of Transport Planning", Volume One, Washington 1971.

Ministry of Communications and Transports "Statistics Yearbook 2002" (in Spanish) México, 2002 (<http://www.sct.gob.mx/>)

Ministry of Communications and Transports "Highway Statistics" (in Spanish). Mexico, 2002. (www.sct.gob.mx).

Ministry of Communications and Transports, "Multimodal Transportation in Mexico", Mexico, January 2003.

Ministry of Communications and Transports, "Highways Classification" (in Spanish). México, 2002 (<http://www.sct.gob.mx/>)

Ministry of Communications and Transports, "Transportation Statistics 2002" (in Spanish). México, 2003 (<http://www.sct.gob.mx/>)

Ministry of Communications and Transports, "Transportation Infrastructure for the Competitiveness in Mexico" (in Spanish). México, 2003.

Ministry of Communications and Transports, General Coordination of Ports and Merchant Marine Mexico. Web Page (<http://e-mar.sct.gob.mx/>), 2004

Ministry of Communications and Transports "Statistics of Maritime Port Sector", México, 2002 (www.sct.gob.mx)

Ministry of Economy, "Commerce Statistics in Mexico" México, 2003
(http://www.economia-snci.gob.mx/sic_php/ls23al.php?s=24&p=1&l=1)

Muller, Gerhardt. "Intermodal Freight Transportation Challenges and Opportunities for an ITS/Intermodal freight Program, Cambridge Systematics, February 1999.

North American Transportation Statistics (NATS) web page
(<http://nats.inegi.gob.mx/nats/>), 2004

Perez, D., Mendoza, A., Garcia, A., Villegas, N., "Vehicle Operating Costs Analysis for Freight Transportation on Federal Highways" (in Spanish). Technical Publication No. 179. Mexican Transportation Institute. Queretaro, Mexico, 2001.

Plan Puebla Panamá Web Page, Ministry of Foreign Affairs, México
(<http://ppp.sre.gob.mx/index.php?Itemid=1>), 2004

Prozzi, J., Spurgeon, K., Harrison, R., "Secret Lives of Containers" Transportation Research Record 1833, TRB, National Research Council, Washington, D. C., 2003.

Reyes, T., "Transportation and Air Infrastructure in Mexico: Current Situation" (in Spanish). Analysis and Investigation Service, Economy and

Commerce. Chamber of Representatives Mexico.
(<http://www.cddhcu.gob.mx/bibliot/publica/inveyana/econycom/aereo.htm>) Mexico, 2000.

Rico, A., "Domestic Air Cargo Transportation in Mexico" (in Spanish).
Technical Publication No. 168. Mexican Transportation Institute.
Queretaro, Mexico, 2001.

Rico, A., Mendoza, A., Mayoral, E., "Applications of Economic Value of
Freight Flows to Transport Planning" Transportation Research Record
1522, TRB, National Research Council, Washington, D. C., 1996.

Rico, A., Mendoza, A., and Mayoral, E. "Main Freight Land Transport
Corridors in Mexico" Transportation Research Record 1613, TRB, National
Research Council, Washington, D. C., 1998.

Rico, O., "Logistics Concept Review". C.L. Foreign Trade, Mexico
(<http://www.exportadora.com.mx/logistica2.html>), 2004

Sayers, M.W., Gillespie, T.D., Queiroz, C.A.V., "The international road
roughness experiment: a basis for establishing a standard scale for road
roughness measurements" Transportation Research Record 1084, TRB,
National Research Council, Washington, D. C., 1986.

Strategis, Industry Canada,

(<http://strategis.ic.gc.ca/engdoc/main.html>), 2004

Sussman, J, "The Customer and Level of Service" Open Course Ware, Civil and Environmental Engineering, Transportation Systems, Fall 2002, Lecture Notes, Massachusetts Institute of Technology.

The Bank of Mexico web page

(http://www.banxico.org.mx/cgi_inveco/ctasascrebd.exe?idioma=esp&SP1=SP1), 2004

"The Logistics System and Freight Level-of-Service" Open Course Ware, Civil and Environmental Engineering, Transportation Systems, Fall 2002, Lecture Notes, Massachusetts Institute of Technology.

The Port of Cutuco, El Salvador

(<http://home.houston.rr.com/nugent/cutuco.html>), 2004

The Port of Coatzacoalcos web page

(<http://www.apicoatza.com/APICOATZA.COM/fotos/index.html>), 2004

The Porto of Progreso web page (<http://www.puerto-progreso.com.mx/elpuerto/progreso.htm>), 2004

The Port of Salina Cruz web page

(<http://www.apisal.com.mx/espanol/atraque/index.htm>), 2004

Transportación Ferroviaria Mexicana, S.A. de C.V.

Transporte Siglo XXI magazine, year 4, volume 37; Mexico, 2004

Transporte Siglo XXI magazine, México, June 2004.

(<http://www.transportesxxi.com/index.php>)

Transporte Siglo XXI magazine, México, July 2004

(<http://www.transportesxxi.com/index.php>)

Valdez, N., Mendoza, A., "STAN Model Development for Freight Transportation on Highways" (in Spanish). Technical Publication No. 206. Mexican Transportation Institute. Queretaro, Mexico, 2002.

Vannieuwenhuyse, B., Gelders, L., Pintelon, L., "An Online Decision Support System for Transportation Mode Choice" Centre for Industrial Management, Université Catholique de Louvain, Belgium, 2002

Washington Asphalt Pavement Association web page

(http://hotmix.ce.washington.edu/wsdot_web/Modules/09_pavement_evaluation/09-2_body.htm), 2004

World Economic Forum web page (<http://www.weforum.org/>), 2003

Zografos, K., Giannouli, I., "Emerging Supply Chain Management Trends and Their Impact on Spatial Organization of Logistical Networks" Transportation Research Record 1833, TRB, National Research Council, Washington, D. C., 2003.

APPENDIX A

MODES OF TRANSPORTATION AND MULTIMODAL/INTERMODAL TRANSPORTATION

A.1 Modes of Transportation: Advantages and Disadvantages

In the late 1980s and 1990s there was an unprecedented increase in international economic activity, commerce, and world-wide transportation. Industrialized countries are an important part of the global economic strategy, and they have been very active in the development of their transportation systems. They consider transportation systems as one of the essential elements of progress that allow them to plan their future investments. Each country attempts to take advantage of development opportunities offered by different modes of transportation based on its geographic and economic conditions. In this context, in Mexico it is necessary to identify and benefit from the specific advantages of each mode of transportation. It is also important to take into account the country's geographic location, which offers great potential for transportation and logistical development.

In order to be able to continue with economic growth, the transportation system must be developed in a sustainable and profitable manner, and it must encourage fair competition between different modes of transportation. There is an urgent need to advance the structural change of transportation in

Mexico. The country's legislation and regulation must be modernized, by adapting it to present transport needs in the global context. Most countries already have modernized and updated their legal and normative regulation for both national and regional level of transportation. For example, the European Community recently enacted legislation and a range of policies that strengthen the single market and increase trade. These include competition policy and regulations to encourage cross-border cooperation between firms and businesses that would allow them to deliver more goods at lower prices. In the last ten years, the Europe Union has opened national transportation markets across the Union to competition, particularly in the road and air transportation and, to a lesser extent, for rail transportation. As a result, trucks can operate in countries other than their own and can carry load from and to any country so they no longer have to return empty on international journeys. "The liberalization of air travel has brought more competition and lower fares as well as an increase of 30 percent in connections between member states since 1993. In March 2003, a first package of measures to liberalize rail infrastructure took effect, opening about 70-80% of rail freight traffic over main lines to competition".(Europe Union, 2004)

Development of modes of transportation depends on the intrinsic characteristics of each mode. For example, the railroad has great potential due two of its basic characteristics, capacity and low cost.

The support given to road transportation and the delayed process of railroad deregulation has resulted in only fifteen percent of terrestrial freight volume being transported by railroad. This means that the opportunity has been lost for improving logistical costs of transportation processes. On the other hand, the railroad helps to improve regional integration for even small amounts of cargo when the freight consolidation process is used.

A.1.1 Railroad Transportation

Railroad transportation provides a relatively fast distribution system, with good reliability and relatively low cost. It is the only mode that can compete with maritime transportation for large freight movements when collection and distribution components are organized. It is the best equipped mode for "door to door" services, and maintains the lowest incidence of accidents between all modes of transportation (Mexican Transportation Institute, 2002).

Railroad Transportation has two main modalities: intermodal and break bulk transportation. The first one is transportation via containers, movable boxes or intermodal equipment, between intermodal terminals using truck transportation to move containers from the place of origin to the intermodal terminals and from intermodal terminals to the final destination. The second modality is transportation of non-containerized merchandise in special wagons depending on the products' characteristics.

Some advantages of railroad transportation are:

- Small costs of transportation.
- Cheaper than truck transportation.
- It does not cause congestion problems.
- Usually terminals are located next to production centers.
- Provides a transportation capacity for high volumes of products.

According to the Ministry of Communications and Transports Mexico, railroad users in Mexico have the option to use the following competition mechanisms:

- Interconnection services between main stations without restrictions for interline freights, where clients create their own cargo routes.
- Access mechanisms to markets established by diverse railroad concessionaires (all railway network), through 64 obligatory rights of use.
- Haul services between railroad concessionaires (interline transportation).
- Access to main cities, markets, ports and crossing borders using railroad routes.

The most common products transported by railroad are: agricultural produce, minerals, petroleum derivatives, iron and steel products and containers. Advanced control systems help to expand the traffic of trains using the same railroad tracks and the same infrastructure, avoiding extra costs for construction of additional tracks.

The United States Department of Transportation (DOT) and the railway industry have been working together to develop an Intelligent Railway System in order to incorporate new digital communication technologies for the Positive Train Control (PTC), as well as brake systems and damage detection. "A PTC system can track the location and speed of a train more accurately than before. By providing better tracking of train location and speed, PTC increases operational efficiency, allows higher track capacity, enhances crew safety, and results in a safer environment for personnel working on the track." (Federal Railroad Administration, 2004)

"Pilot versions of the PTC were successfully tested a decade ago, but the systems were never deployed on a wide scale. Other demonstration projects are currently in the planning and testing stages. Deployment of PTC on railroads is expected to begin in the last years of this decade". (Federal Railroad Administration, 2004)

A.1.2 Truck Transportation

The main advantage of truck transportation comes from use of a universal road infrastructure, where access to any point from origin to destination reduces cargo transfers.

This system is very versatile and can be used by small or big trucks. It has the capacity to move small or large product volumes no matter what kind of products: solids, gases or liquids. Technically, truck transportation is not the fastest mode of transportation; however, loading and unloading facilities, and schedule flexibility make it an adequate mode of transportation for urgent shipments, mainly for the domestic market.

In terms of ton-kilometer transportation costs, truck transportation ranks between air transportation (high cost), and marine or railroad transportation (low or relatively low cost).

Truck transportation is characterized by reliable product delivery, with connections between multimodal and intermodal terminals. It is highly recommended for short and medium distances for export/import of goods.

Some other advantages of the truck transportation are:

- direct and safe delivery of products,
- minimum handling of products,

- fast delivery for short distances, and
- simple and inexpensive packing.

According to information provided by the National Association of Freight Truck Transportation Mexico (CANACAR), the disadvantage of truck transportation is that in Mexico almost all truck fleet is obsolete. Around 18 percent of the total fleet is more than 25 years old, 12 percent is between 11 and 15 years old, and only 14 percent under five years old. In spite of this situation, some carrier companies are using new concepts and new technologies to become first class fleets. These new technologies and new concepts include: unit renovation, powerful electric motors, use of double vehicles and load and unload innovation systems. (Altamirano, 2001)

Increasing pressures for fast delivery and direct access to final customers have meant that road transportation has been favoured in the past years. Nowadays, this situation has generated many problems such as congested roads, multiple traffic accidents, and uncontrollable pollutant emissions.

A.1.3 Air Transportation

For many years air cargo transportation was greatly constrained by the lack of efficient operating aircrafts. This situation restricted air freight to become a significant competitor of freight transportation. Also, air freight could not become a part of the intermodal/multimodal transportation. Introduction of wide body aircrafts like the Boeing 747 changed everything; airlines realized

the remarkable potential of freight transportation with new aircraft that were able to carry containers and standardized equipment. This made air transportation a new competitor in terms of transportation.

In 1976, about 9.3 million tons of freight were carried by air, and in 1985 this value increased to 13.2 million tons of freight carried on international and domestic air routes (International Civil Aviation Organization, 1986). Boeing forecasts that freighter fleet will grow from 1,775 airplanes at the end of 2001 to nearly 3,100 airplanes by 2021. According to Boeing, *"with the significant replacement of many medium-size, standard-body freighters by medium-size wide bodies, it is not surprising that the forecast shows a tripling of that latter category in terms of fleet units"* (see Figure A.1). Currently, combined wide body segments comprise nearly 40 percent of world's total freighter units. But the wide body share of fleet in the world will grow to 60 percent of all fleet by 2021 (Boeing, 2003). Because of the disparity in capacity between standard-body and wide body airplanes, the wide body fleet's share of the world's total capacity will increase from 80 percent today to 90 percent by 2021. (Boeing, 2003)

Figure A.1: Freight Aircrafts Development (Source: Boeing, 2003)

Boeing also forecasts that the World Air Freight Market will more than triple in 20 years with a base average annual growth of 6.4 percent (Figure A.2), and that World Air Cargo will grow at 6.4 percent per year for the next 17 years as shown the in Figure A.3.

Figure A.2: Air Freight Market Growth (Source: Boeing, 2003)

Figure A.3: Air cargo Growth (Source: Boeing, 2003)

Air Cargo transportation can be an expensive service compared to other modes of transportation. However, it is an essential mode of transportation for an economy.

Some of its most important advantages are described below:

1. Number of flights per week or per month is considerably greater than the frequencies for other modes of transportation.
2. Cargo transfer from one flight to another is faster than the equivalent move between other modes of transportation.
3. The use of special containers and improvements in ground facilities at airports have helped to increase cargo volumes.
4. Speed of transport for some products is not just a benefit, it is a critical consideration. Some of these products are:

- Products with a biological constraint such as flowers and some fruits.
 - Emergency shipments such as medicines and first aid equipments.
 - Important documents that need to be delivered on a specific day or at specific time.
 - Specialized equipment or broken machine parts that must be shipped from another city or a foreign country in order to be replaced.
5. Access to specific markets not available for other modes of transportation.
6. Reduction in storage costs.

From the top ten U.S. airports for air cargo, only three saw an increase in volume in 2002. It is no coincidence that two of them, Memphis, Tennessee, and Louisville, Kentucky, are hubs for FedEx and UPS, respectively. The reason that Memphis and Louisville airports have grown in volume is that they are hubs for these two courier companies. "FedEx and UPS ship about 60 percent of U.S. cargo, and this volume has been growing, especially at Memphis, as a result of the contract FedEx has with the U.S. Postal Service to ship much of its mail." (Atkinson, 2003)

Mr. Juan Manuel Rodriguez Anza, the current President of Estafeta (Mexican Courier Company) said that this type of transportation still has great problems in Mexico. Some of these problems are: nonexistent airport infrastructure for this type of service, high costs for night operations, and closed airports at nights.

A.1.4 Maritime Transportation

Maritime transportation is essential for a country's economic development and it is the most frequently used mode of transportation for international commerce. Among all modes of transportation it is least expensive and most environmentally-friendly. It can easily transport large volumes of products between distant zones or regions. There are different sizes and types of vessels according to the type of cargo, volumes and destinations. The system in general is slow; nevertheless, it is ideal for transportation of large volumes and inexpensive products.

The techniques for handling containers at ports have been substantially improved in recent years. This has facilitated load and unload operations, increasing efficiency and reducing the length of time that vessels stay in ports.

Despite the advantages of maritime transportation, the sector has experienced serious problems during recent years due to international economic conditions and a decrease in maritime freight rates. This has

resulted in high competition between shipping lines (Lecona, 2003). With this situation Mr. Jorge Lecona said *"the five most important shipping lines of the world reported financial losses in the years 2000 and 2001; and for the 2002, the deficit was greater"*. (Lecona, 2003)

Maritime freight consolidation permits the reduction of transportation costs for exporters and importers. This means that the shipper will pay for only the space used for the shipment. This technique is well known as "boxrate" and is widely used by consolidation agents to divide the total container cost among all interested shippers.

The problem with maritime transportation is that it requires huge facilities and infrastructure to operate and it is a slow mode of transportation.

A.1.5. Multimodal/Intermodal Transportation

Multimodal freight activity is the movement of goods that involves various modes of transportation during a single trip. Different combinations of modes are used to ship goods; therefore multimodal freight activities require terminals and appropriate highways, rail, waterway, and runway access to link these facilities to the national transportation system. The objective of multimodal and intermodal transportation is the efficient transfer of goods (low cost, low time) from origin to destination (door to door service) using all modes of transportation in a continuous flow.

Multimodal transportation is very complex because all modes of transportation must be coordinated; therefore attention is mainly focused on how to increase capacity and efficiency in order to satisfy the demand. Multimodal and intermodal freight activity has brought many benefits including a reduction in transportation costs, highway congestion, and air pollution. Some other benefits are listed below:

- Lower overall transportation costs by using each mode for the most appropriate portion of the trip.
- Increased efficiency and economic productivity due to the use of the most appropriate mode of transportation.
- Reduced congestion over the saturated highway infrastructure.
- Reduced energy consumption.
- Improvement of environmental conditions like air quality.
- Reduction in logistics costs
- Just in time delivery (optimal frequency service and modal choice) reduces the burden of inventory holding costs.

Multimodal issues arose in the 1960's and 1970's when environmental and energy supply problems increased (Muller, 1999). This is because the more efficient the transportation the less consumption of energy. There is also less damage to environment which means conservation of natural resources.

Sometimes the movement of goods is made with an *intermodal container*. This means that goods are consolidated in a container that fits in almost all modes of transportation. There are some exceptions like airplanes, in which space for cargo transportation is lower and the shape of the airplane doesn't allow them to be accommodated, therefore other type of containers are used. Containers offer many advantages such as unitized freight (consolidated), protecting it from weather, external damage and robbers, and making it easier to load and unload to and from vehicles. There are also many disadvantages such as cost of rental, repair, maintenance, as well as incompatibility with some vehicles.

General and bulk cargos are the two major categories of cargo. General cargo represents products like machinery, vehicles, packaged goods and equipment. Other products like coal, grains, iron ore, and petroleum are classified as bulk cargo.

Multimodalism or intermodalism can be considered problems due to the difficulties of transferring goods between different vehicles and between different modes of transportation. Vehicles for each mode of transportation

are different and sometimes goods are subject to different stresses and shocks affecting the physical conditions of goods. Occasionally goods or products stay a long time at interchange points or intermodal terminals so intermodalism or multimodalism is then substituted by warehousing. For this reason, one of the challenges of multimodalism/intermodalism is to keep goods moving while they are being transferred from one mode to another.

The elements of intermodal/multimodal freight systems are shown in Table A.1. The four most important factors for intermodal/multimodal freight transportation are: (Muller, 1999)

1. a transportation system (roads, railway tracks, waterway),
2. terminals where cargo transfers between modes (Cargo terminals, intermodal terminals),
3. vehicles and units that carry cargo (containers, pallets, etc), and
4. regulatory structure of the transport industry.

Table A.1
Elements of the intermodal/multimodal freight system.

	Air	Rail	Water	Road
Carriers	Air cargo carriers	Railroads	Shipping lines	Motor carriers
Conveyance	Airplanes	Trains	Ships and barges	Trucks
Terminal	Airports	Rail terminals	Ports	Truck terminals
Infrastructure	Airways	Railways	Sea and inland waterways	Roadways

Source: Muller, 1999

Currently, modal systems operate independently of each other and sometimes cooperatively, but each largely retains its own distinct ownership and operating patterns. This causes serious problems for the intermodal/multimodal chain affecting the transportation service and customer's reliability (intermodalism/multimodalism is attempting to change that). Airports, ports, shipping lines and railroads undertake investment programs. These firms seek to maximize their net revenue taking into consideration the behavior of carriers and competition between rival shipping companies.

APPENDIX B

TRANSPORTATION INFRASTRUCTURE IN MEXICO

B.1 Facts and General Characteristics

According to the "Competitiveness Analysis in Mexico", a research project developed by the Mexican Institute of Competitiveness, all modes of transportation are operating inefficiently due to inadequate infrastructure and a lack of regulation. "High costs of transportation logistics are a consequence of an old and obsolete infrastructure, as well as of an inadequate regulatory scheme that does not promote competition between all modes of transportation" (Mexican Competitiveness Institute, 2004). The results of the IMCO study confirm that air cargo transportation in Mexico shows a small degree of development, whereas Panama and Colombia are more efficient than Mexico.

Grupo Modelo, one of the leading companies in Mexico with exports to over 150 countries, says that Mexico has lost competitiveness due the lack of adequate transportation infrastructure. "We are competing in the worldwide market but we are losing. The transportation infrastructure in Mexico, including roads and railways, is obsolete compared with the transportation infrastructure of other countries like those in Asia. This is preventing us from growing in the worldwide market." (Aramburuzabala , 2004)

B.2 Air Transportation

"The potential for air cargo transportation in Mexico is immense because it almost does not exist". Last year, there were considerations to build a new refrigerated terminal at the international airport in Monterrey, Mexico. According to Jean Yves Carrasco, Operations Director of North Center Airport Group Mexico, "air cargo in Mexico is an area with huge potential."

B.3 Truck Transportation

Eighty-six percent of domestic freight in Mexico is moved by ground transportation (trucks and railroad). The cost of this mode of transportation has increased significantly due expensive toll roads. This situation has made Mexican road freight transportation one of the most expensive in North America and Europe. "An evaluation of toll costs on the main roads of the country shows that these figures are an important part of the total transportation costs" (Mexican Competitiveness Institute, 2004). The cost increases are also caused by the high prices of fuel, financing, insurance, maintenance, and licenses. In Mexico, fuel and credit expenses are 61.5 percent and 50 percent respectively. These figures are much higher than those of United States, while the operators' salaries are significantly lower in Mexico (Mexican Competitiveness Institute, 2004).

B.4 Maritime Transportation

The World Economic Forum was categorical in its ranking of Mexican ports: "Mexican port infrastructure is ranked below the average of 75 countries, and below its commercial partners with an average score of 3.3." (World Economic Forum, 2003)

The Competitiveness Analysis made by the Mexican Competitiveness Institute (IMCO), stated that with the privatization of Mexican ports, investments in this sector increased. However, the operating efficiency remains low and the main operations are concentrated in just a few ports. This has a negative impact on sector competitiveness. The containerized freight movement in Mexico is concentrated in five ports (Veracruz, Manzanillo, Altamira, Tampico and Progreso). These ports handle 95 percent of the total maritime freight of the country.

As a result of more competitive tariffs for maritime movements, many international shipping companies enter the Mexican market through the country's ports. Nevertheless, "Mexico has high port services costs, principally those corresponding to port operations. This affects the competitiveness in marine transportation" (Mexican Competitiveness Institute, 2004).

The Ports of Veracruz and Manzanillo are the largest ports in the country, but they are the most expensive ports in the world. Their tariffs are higher than those of the most efficient terminals in the world, such as the Port of Rotterdam and the Port of New York, NY. The tariffs at Veracruz Port are 155 percent higher than those at the Southampton Port, 110 percent higher than those at the Port of Rotterdam, 85 percent higher than those at the Port of Hamburg, and seven percent higher than those at the Port of Tokyo. (Mexican Competitiveness Institute, 2004).

B.5 Railroad Transportation

Mexican railroad infrastructure was abandoned for more than five decades. This has made its infrastructure inferior to that of other countries like China, United States, Poland and Brazil. The Mexican railroad map shows a terrible situation: there are insufficient routes to the United States and there are no major routes connecting the south of the country with Central and South America. This situation negatively affects commerce in Mexico. Hence, the country has two possible options to solve this problem: it can either expand its railroad network or optimize its logistics chains.

The Competitiveness Analysis in Mexico made by the Mexican Competitiveness Institute (IMCO) also indicates that the competition levels between railroad companies are very low. This is due to some of the current policies, like the “permissions movement”, which places restrictions between

a company's railways, as well as a "hauling services policy" that does not facilitate competition. Furthermore, a regulatory body is not in place to address and solve problems and conflicts between railroads concessionaires, and between them and their users. This results in low quality of services due to extended travel time and infrequent service delivery.

As the other modes of transportation, the Mexican railroad sector offers higher tariffs than those of its commercial partners in Canada and the United States. The railway tariffs for an average distance of one thousand kilometers are 140 percent higher than the tariffs in the United States and 40 percent higher than in Brazil (Mexican Competitiveness Institute, 2004).

B.6 Transportation Infrastructure in Mexico

The structure of transportation in Mexico has undergone many changes, including the privatization of all modes of transportation (such as railroads, airports, maritime ports and part of the major highways) that took place in the 1990's. This privatization was essential for infrastructure development and for future investments. The infrastructure for each mode of transportation is very particular and will be described briefly in the following section.

B.6.1 Railroads

In the past, the railroad was totally operated by Mexican National Railroads (a Government Company), but at the end of the 1990's it was privatized and divided into four different regional companies.

In June of 1997, two companies, the Kansas City Southern and Transportacion Maritima Mexicana (Mexican Maritime Transportation), won the tender for the Northeast Railway and formed Transportacion Ferroviaria Mexicana (Mexican Railway Transportation), with a railway route of 3,960 kilometers. Grupo Mexico (Mexican Group) and Union Pacific took control of the North Pacific Railway and formed Ferromex Company, with a railway route of 6,200 kilometers. The third company formed was Ferrosur, which currently controls part of the Southeastern Railroad, operating 2,200 kilometers of routes. Ferrosur is owned by Frisco, a division of the Mexican Holding Carso. The fourth company formed was the Chiapas-Mayab Railroad controlled by the Genesee Wyoming Inc. with a rail network of 1,805 km located in southeast Mexico (Centeno et al., 2003).

How did this process of privatization affect investments in the railroad sector? Figure B.1 shows the investments made from 1994 to 2002. It is clear that investments increased after 1997 when the privatizations took place.

Figure B.1: Railroad Investment in Mexico

(Source: Transporte Siglo XXI, 2003)

Current Infrastructure

The railroad network connects 30 different federal regions, urban, agricultural, and mining centres, as well as industrial areas, maritime ports and borders. The railway network is 26,613 km long (Center for Business Information and Documentation in Iberoamerica, 2002); approximately 20,000 of which are classified as main routes that connect the country's major economic centers. Only 40 percent of these are classified as modern routes (continuous welded high caliber rails supported on concrete sleepers or crossties), while 38 percent corresponds to a classic or traditional routes (110 lb/yd rails), and 22 percent are rarely used (low caliber rails).

According to the Transportation Statistical Manual (2001) published by the Mexican Transportation Institute, the available tractive equipment in Mexico in 2000 included: 1,446 locomotives, 135 passengers cars, and 30,635 freight cars (double-door boxcar, open hopper, platforms, gondolas, etc).

Table B.1 shows the evolution of the railway routes from 1990 to 2000. We can observe from this table that the total constructed kilometers during the last ten years was 294.

Table B.1
Current rail tracks length

Year	Main Tracks	Secondary Tracks	Privates Tracks	Total	Wide Tracks	Narrow Tracks
1990	20351	4537	1473	26361	26182	179
1991	20324	4537	1473	26334	26163	171
1992	20445	4460	1540	26445	26274	171
1993	20445	4460	1540	26445	26310	171
1994	20447	4460	1540	26447	26445	167
1995	20687	4380	1545	26612	26455	167
1996	20687	4380	1555	26622	26445	167
1997	20687	4380	1555	26622	26455	167
1998	20687	4380	1555	26622	26445	167
1999	20687	4380	1555	26622	26455	167
2000	20687	4413	1555	26655	26445	145
2001	20687	4413	1555	26655	26445	145
2002	20687	4413	1555	26655	26445	145

Source: Mexican Transportation Institute, 2003

Figure B.2 shows the current railway network structure.

Figure B.2: Current Railway Network in Mexico

(Source: Ministry of Communications and Transports Mexico, 2003)

B.6.2 Airports System

In 1987, the airport system faced important financial, administrative and operative problems. The demand for national services fell, and coupled with rigid operative structures, this provoked a decrease in the supply of air service. This situation forced the Ministry of Communications and Transports to create and publish the "National Air System Transportation Governing

Scheme” in April 1988. This document included a proposal for a new structure for national aviation.

The reconstruction of the air transportation system began immediately and the two main airlines in Mexico changed the way in which services were offered, focusing on the resurgence of regional aviation. Important events took place during the reconstruction process, including the bankruptcy of the Aeronaves de México (one of the main airlines) in May 1988, and its substitution by the private company Aerovías de México (Aeroméxico) in October of the same year. The privatization of Mexicana de Aviación (the second main airline) was announced in August 1989 (Heredia, 1999). Refer to Table B.2.

Table B.2
Evolution of Registered Mexican Airlines (1987 – 2003)

	Type of Airlines	1987	1992	1996	2003
Domestic	Passengers and freight	8	18	16	9
	Freight	0	5	6	8

Source: Heredia, 1999

Like other transportation infrastructure, aeronautical infrastructure was privatized in the 1990's increasing the investment possibilities in this sector. General regulations for this process were published in the “Diario Oficial de la Federacion” (Federation Official Newspaper) in February 1988.

In order to complete this privatization, four airport groups were created: Grupo Aeroportuario Centro-Norte (Center-North Airport Group), Grupo Aeroportuario Ciudad de México (City of Mexico Airport Group), Grupo Aeroportuario del Pacífico (Pacific Airport Group) and Grupo Aeroportuario del Sureste (Southeastern Airport Group). These four groups control the 35 main airports of the country that represent 60 percent of all airports. In 1995, these 35 airports handled 96.8 percent of the total passengers and 95.8 percent of the total freight (Heredia, 1999).

The Airports System was divided into four different groups:

1. The Southeastern Airport Group (ASUR) has eight airports and is jointly operated by the Airport of Copenhagen. This Group is headquartered in Cancun, Quintana Ro, Mexico.
2. The Pacific Airport Group (GAP) has eleven airports and is jointly operated by the Multinational Spanish AENA. This Group is headquartered in Guadalajara, Jalisco, Mexico.
3. The North Center Airport Group (OMA) has thirteen airports and is headquartered in Monterrey, Nuevo Leon, Mexico. This Group is jointly operated by the French Company ADP.

4. The Central Region Group operates the Mexico City International Airport (AICM), and it is the most important airport in the country. Currently, the Mexican Government is defining a strategy to replace this airport. Meanwhile, the operators will have to improve and expand the current airport facilities.

Current Infrastructure

From 1995 to 1999 the statistics for this sector revealed the following tendencies:

- ✓ Domestic passenger transportation increased 25.7 percent, with an increase from 29.8 million in 1995 to 37.46 million passengers in 1999.
- ✓ The freight transportation increased 8.2 percent, from 218.4 thousands tons in 1995 to 236.3 thousand tons in 1999.
- ✓ The total fleet was reduced from 6,426 to 6,224 units, representing a reduction of 3.14 percent.
- ✓ There were 1862 airports in 1995 and 1357 airports in 1999; this represented a decrease of 27 percent (Mexican Transportation Institute, 2002).

As a consequence of the decrease in airport infrastructure and the increase in passengers and freight movement some problems were identified by the sector authorities including runway congestion and saturation of terminal buildings.

In 1995, national airports represented 1.1 percent of the total airport network, 2.3 percent represented international airports, and 92.7 percent represented aerodromes. In 2000, the numbers were 1.9 percent, 2.18 percent and 91.2 percent respectively. During the 1995-2000 period, the number of airports was reduced by 33.5 percent (from 1862 airports in 1995 to 1239 airports in 2000) (Airports and Auxiliary Services, 2004). The reason for this change was that in 1996 several aerodromes did not renew their operation licenses, therefore they were closed down. Also, from 1992 to 2002 the national airport network was reduced by 25 percent (from 20 down to 15 airports) and the international airport network was enlarged by 18.4 percent, (from 38 airports in 1992 to 47 airports in 2002). In total there are 62 airports in Mexico (15 domestic and 47 international) (Ministry of Communications and Transports, 2003).

In the year 2000 Mexico's City International Airport ranked first in terms of airport movement. This airport transported 39.17 percent of all passengers in the country and 35.45 percent of all freight (Mexican Transportation Institute, 2002).

Figure B.3 shows the main airports in Mexico and Figure B.4 shows the airports distribution for each private group.

Figure B.3: Current Airport Network in Mexico

(Source: Ministry of Communications and Transports Mexico, 2003)

Figure B.4: Airport Distribution in Mexico

(Source: Ministry of Communications and Transports Mexico, 2003)

B.6.3 Highways System

Mexico's national transportation system is fundamentally based on road transportation. The road network has had an important growth not only in infrastructure but also in freight movement, and national economic participation. However, road infrastructure continues to be characterized by large technological, operational and administrative deficiencies. It is crucial that these deficiencies be addressed in a timely manner using new technologies that will promote development.

Current Infrastructure

According to Federal Highways and Bridges (CAPUFE) data, Mexico has a road infrastructure that extends for 365,119 km. More than 60 percent of freight and 98 percent of passengers are transported via 50,000 km of a federal paved road network. This network is commonly referred to as the Basic Federal Network, and it provides a great deal of support for the country's economic activities. This network is formed by 44,000 km of free highways, and 5,683 km of toll roads (Anaya et al., 1999).

The use of the highway network has been increasing during the past few years with an annual growth of 9 percent (Federal Highways and Bridges, 2002). Figure B.5 shows lengths and characteristics of roads for the period 1992 to 2002. Note that for this period there is an increase of almost 100,000 km of new roads.

Figure B.5: Length and characteristics of the highway network

(Source: Ministry of Communications and Transports Mexico, 2002)

Currently, most of the highways are operated by the Federal Government and just a few are operated by private companies. The road network can be classified in free and toll highways, and in Federal, Provincial and Rural. There are 48,288 federal roads, 65,860 provincial roads and 162,085 rural roads.

Figure B.6 shows the main roads in Mexico.

Figure B.6: Main Roads in Mexico

Source: Ministry of Communications and Transports Mexico, 2003

B.6.4 Maritime Ports

Worldwide commercial traffic is critical for the growth and development of all countries. Therefore, in Mexico it was necessary to establish a transportation system including maritime ports that could support this commercial traffic. In order to respond to such demands, the process of port reconstruction process started in the second half of the 1980s. This reconstruction included operation, infrastructure and equipment improvements. Finally, in 1993, the

Port's Decentralization and Privatization Legal Policy was issued (Ley de Puertos, 1993) (Martner et al., 2000).

This reconstruction also implied a deep sector transformation. The participation of the private sector brought many benefits for the main ports, like investments, infrastructure and equipment modernization. The Port of Veracruz, the foreign trade port leader, benefited a great deal from these resources and innovations. During the second half of the 1990s, this port underwent great improvements in operation efficiency using standards for the containerized operation similar to those recognized worldwide.

Nevertheless, integration with other modes of transportation is very inefficient. The port's logistics chains still experience some difficulties such as delays, unnecessary times of freight immobilization and additional costs for operators and users.

Current Infrastructure

There are 54 maritime ports in the country (Figure B.7), 36 of which are the most important. These 36 ports and some of their characteristics are described in Table B.3.

Figure B.7: Current Maritime Ports in Mexico

(Source: Ministry of Communications and Transports Mexico, 2003)

Table B.3
Maritime ports characteristics

	Port	Provided Services			
		Commercial	Fish	Tourism	Other
Pacific Coast	El Sauzal, B.C.	X	X		
	Ensenada, B.C.	X	X	X	X
	Isla Cedros, B.C.	X	X		X
	Rosarito, B.C.				X
	Guerrero Negro, B.C.S.	X			X
	Isla San Marcos, B.C.S.	X			X
	La Paz, B.C.S.	X		X	X
	Pichilingue, B.C.S.	X	X	X	X
	Santa María, B.C.S.	X			
	San Carlos, B.C.S.	X	X	X	
	Santa Rosalía, B.C.S.	X	X	X	X
	Manzanillo, Col.	X		X	X
	Puerto Madero, Chis.	X	X		X
	Acapulco, Gro.	X	X	X	X
	Lázaro Cárdenas, Mich.	X	X		X
	Salina Cruz, Oax.	X	X		X
	Mazatlán, Sin.	X	X	X	X
	Topolobampo, Sin.	X	X	X	X
	Guaymas, Son.	X	X	X	X
Gulf of Mexico and Caribbean	Cayo Arcas, Camp.				
	Cd. del Carmen, Camp.	X	X	X	X
	Lerma, Camp.		X		
	Seybaplaya, Camp.	X			
	Cozumel, Q. Roo			X	
	Isla Mujeres, Q. Roo		X	X	
	Puerto Morelos, Q. Roo	X	X	X	X
	Punta Sam, Q. Roo				
	Punta Venado, Q. Roo	X		X	
	Dos Bocas, Tab.				X
	Altamira, Tamps.	X			
	Tampico, Tamps.	X	X	X	X
	Coatzacoalcas, Ver.	X	X	X	X
	Pajaritos, Ver.	X			X
	Tuxpan, Ver.	X	X	X	X
	Veracruz, Ver.	X	X	X	X
	Progreso, Yuc.	X		X	

Source: Ministry of Communications and Transports Mexico, 2002

B.7 Intermodal/Multimodal Infrastructure in Mexico

Mexico's intermodal and multimodal infrastructure has had an important development in recent years. Currently there are 54 terminals with the following distribution: 26 intermodal terminals, 13 multimodal terminals, 12 multimodal and intermodal terminals and three container depots (Refer to Figure B.8) (Guadalupe et al., 2003). According to their location, there are 19 port terminals and 48 land terminals. The 48 land terminals are divided into 45 intermodal or multimodal terminals and three container depots. There are 12 private terminals and 55 public terminals (Guadalupe et al., 2003). The operations of almost eighty percent of these terminals started after 1993, and approximately 50 percent of these terminals were further developed in 1996 when railroad privatization took place. (Refer to Figure B.9).

Figure B.8: Intermodal and Multimodal Terminals Location

(Source: Guadalupe et al., 2003.)

Figure B.9: Terminals Growth

(Source: Guadalupe et al., 2003.)

B.7.1 Terminals Size

The average operation surface of intermodal terminals is 11.7 hectares, and the average surface for the all other terminals is 8.1 hectares (the average for public terminals is 11.6 hectares and for private terminals is 3.2 hectares). The operating surface of port terminals is 20.4 hectares, and the empty container deposits account for an average of 0.75 hectares. The average operation surface of multimodal terminals is 5.9 hectares. The average surface of terrestrial terminals is 6 hectares (the average for public terminals is 5.6 and for private terminals is 10 hectares) and the port terminals average surface is 5.6 hectares (Guadalupe et al., 2003).

B.7.2 Terminals Hinterland

Hinterland refers to the market area served by the terminal. The following definition clearly describes the concept: "The hinterland is a land space over which a transport terminal, such as a port, sells its services and interacts with its clients. It accounts for the regional market share that a terminal has relative to a set of other terminals servicing this region. It regroups all the customers directly bounded to the terminal. The terminal, depending on its nature, serves as a place of convergence for the traffic coming by roads, railways or by sea/fluvial feeders." (Slack et al., 2003)

An analysis of the hinterland conducted by the Mexican Transportation Institute shows that there is an intermodal terminal and a multimodal terminal for each hinterland. The analysis also defined a primary hinterland for main clients, and a secondary hinterland for sporadic clients. Figure B.10 shows the primary and secondary hinterland overlap for intermodal terminals, and Figure B.11 shows this same overlap for multimodal terminals. The colour code in these figures shows the number of overlaps. The areas with greater overlaps correspond to regions or zones covered by the greatest number of terminals and vice versa.

It can be observed that the northeastern part of Jalisco has the highest amount of overlap. On the other hand, Baja California Sur, Chihuahua, Durango, Hidalgo, Tlaxcala and Guerrero are not included in the primary cover. Instead, these states are covered in a secondary way, with the exception of Guerrero, which is covered in a primary manner. This is due, in part, to the lack of railway infrastructure, particularly in the states of Baja California Sur, Guerrero and Quintana Roo.

The secondary hinterlands with the most overlap are located in Mexico City and Monterrey. The states not covered by a secondary hinterland are Baja California, Jalisco, Veracruz, Puebla, Oaxaca, Guerrero and the Yucatan Peninsula (Guadalupe et al., 2003).

Figure B.10: Primary and Secondary Hinterland Overlaps for Intermodal Terminals

(Source: Guadalupe et al., 2003.)

It can be observed that all of the country, with the exception of Guerrero, is covered by some of the hinterlands. In fact, Guerrero is the only state with no railway infrastructure and no industrial ports that would allow for multimodal and intermodal transportation. Both the southeastern part of the country and Baja California have the smallest hinterland overlap and/or the lowest demand of intermodal services. The major hinterland overlap is in the western side of the middle part of the country.

Most of primary hinterland overlap for multimodal terminals occurs in Querétaro. The states that are not included in the primary cover of these

terminals are Baja California, Chihuahua, Durango, Oaxaca, Chiapas and Guerrero.

The north of the country is almost completely covered by the secondary hinterland, with the exception of Baja California. On the other hand, the south and southeastern parts of the country are not covered by any of the multimodal terminals. All of the country except for Baja California, Oaxaca, Chiapas and Guerrero is covered by one of these hinterlands (primary and secondary) Refer to Figure B.11.

We can conclude that there is a low demand for multimodal services in the northern and southeastern parts of the country, and this is due to the lack of multimodal terminals and transportation infrastructure. The western side of the middle part of the country is completely covered by multimodal services with primary and secondary hinterland overlaps.

Figure B.11: Primary and Secondary Hinterland Overlaps for Multimodal Terminals

(Source: Guadalupe et al., 2003.)

According to the multimodal and intermodal analysis made by the Mexican Transportation Institute, one hundred percent of the terminals can be accessed by road, eighty two percent have railroad connections, and only twenty seven percent have maritime access. Railroad-road links exist in all multimodal and intermodal terminals, and all maritime terminals have maritime-road and maritime-railroad links. Container depots can only be accessed by road (Guadalupe et al., 2003).

Figure B.12 shows the multimodal system in Mexico including terminals, main highways, railways and future terminals.

Figure B.12: Multimodal System in Mexico

(Source: Ministry of Communications and Transports, 2003)

APPENDIX C

COMMERCIAL ACTIVITY IN MEXICO

Mexico is a country with an area of 1 964 375 km², a population of 100.9 million (2001) and a population growth rate of 1.7 percent per year (National Institute of Statistics, Geography and Informatics, 2003). Some of the most important economic numbers for the year 2001 in Mexico were:

- GNP: US \$572.8 billion and US \$5 892 per capita yearly
- Economy growth rate: 1.3 percent.
- Total exports: US \$158 546 million.
- Total imports: US \$168 276 million.

Mexico has many economic activities and transportation is one of the most important activities. The following table shows the main economic activities in Mexico for the period 1989 – 1999.

Rank	Main Economic Activities	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	1989-1999
1	Commerce	168,573	177,182	183,675	189,174	187,028	198,742	167,006	179,249	200,053	212,660	222,510	2.87 %
2	Rent of real estate	106,940	111,287	116,209	121,290	126,362	130,887	135,073	139,311	142,616	145,456	149,949	3.53 %
3	Transportation	80,302	81,861	83,802	85,404	87,186	93,184	85,923	91,532	101,227	106,697	111,959	3.49 %
4	Metallic products and machinery	44,107	49,038	53,022	56,333	54,001	57,611	51,695	63,208	75,254	83,894	89,668	7.68 %
5	Educational Services	57,245	58,817	60,139	61,047	63,534	64,213	65,141	66,263	67,405	69,078	70,441	2.05 %
6	Food, beverages and tobacco	51,188	53,509	55,234	57,489	59,297	61,240	61,267	63,313	65,364	69,676	72,470	3.93 %
7	Construction	43,995	48,040	50,385	53,754	55,379	60,048	45,958	50,449	55,132	57,461	60,329	3.07 %
8	Other social and personal services	46,916	48,497	50,922	52,174	52,596	54,016	51,517	53,042	54,968	57,290	59,501	2.60 %
9	Agriculture	45,048	48,510	48,888	48,055	49,659	50,262	52,004	54,566	54,429	56,404	57,377	2.15 %
10	Public administration	42,203	42,252	44,665	43,565	43,919	44,686	44,257	43,962	44,384	43,279	43,824	0.39 %
11	Medical services	39,482	40,166	41,149	41,455	42,341	42,843	42,401	41,559	43,501	45,798	46,524	1.66 %
12	Chemicals and products derived from petroleum	33,279	34,725	35,060	35,684	35,075	36,270	35,935	38,297	40,911	43,389	44,415	3.50 %

Table C.1: Main economic activities in Mexico from 1989 to 1999

(Source: Created with data from the Mexican Transportation Institute, 2002)

C.1 Commercial Trades

Economic growth of a country depends on commercial trade. Like other countries in the world, Mexico has signed 32 trade agreements with different countries around the world, including the United States, Canada, and the European Union. New trade agreements are in progress with countries like Japan, Panama, Ecuador and Peru. As an exporter, Mexico is ranked first in Latin America and thirteenth in the world (Altamirano, 2001). The country ranks tenth in the world in terms of GNP, 54th in terms of transportation infrastructure, and 55th in terms of competitiveness (Altamirano, 2001). For these reasons, an efficient transportation infrastructure and the establishment of new and better regulations is essential.

According to transportation infrastructure, Singapore is ranked second in the list, the United States is ranked ninth and Canada is ranked twelfth. The criterion used to make this ranking was based on railroad, airport and highway infrastructure as well as transportation credit access (World Economic Forum, 2002).

Before the 1980's, Mexico had a commerce policy of import exchange that included high tariffs and large processes to obtain import permits. This situation resulted in limited development of trade between United States and Mexico. In the middle of the 1980's this commerce policy changed and the General Agreement on Tariffs and Trade (GATT) between Mexico and United States stimulated commerce between both countries. This resulted in the

following: exports increased from US \$12.39 billion in 1986 to \$56.76 billion in 1996, and imports increased from US \$17.56 billion in 1986 to \$72.96 billion in 1996. In 2002, these numbers had further increased to US \$85.16 billion for exports and \$114.38 billion for imports (McCray, 1998). Exports from United States to Mexico and imports from Mexico to the United States according to mode of transportation for the period 1994 to 2002 are shown in Figure C.1 and Figure C.2 respectively.

It can be observed that exports from the United States to Mexico grew by more than 50 percent and exports from Mexico to the United States doubled. Since the implementation of NAFTA, trade between Canada and Mexico has more than tripled and Mexican exports to Canada have grown by more than 50 percent. Figures C.3 and C.4 show the growth of commerce (imports and exports) between Canada and Mexico from 1994 to 2003.

Figure C.1: Exports from United States to Mexico by mode of transportation
 (Source: Created with data from Bureau Transportation Statistics, 2003)

Figure C.2: Imports from Mexico to United States by mode of transportation
 (Source: Created with data from Bureau Transportation Statistics, 2003)

Figure C.3: Exports from Canada to Mexico in the last ten years
 (Source: Created with data from Statistics Canada and Industry Canada, 2004)

Figure C.4: Imports from Mexico to Canada in the last ten years
 (Source: Created with data from Statistics Canada and Industry Canada, 2004)

Mexico is a formal member of various economic groups, including ALADI (Latin American Integration Association), which is the largest Latin-American group of economic integration. This Association is made up of twelve countries: Argentina, Bolivia, Brazil, Chile, Colombia, Cuba, Ecuador, Mexico, Paraguay, Peru, Uruguay and Venezuela (Refer to Figure C.5). Together they represent a total of 20 million km² and more than 430 million people (ALADI, 2004). The 1980 Montevideo Trade (TM80) is the global legal framework that constitutes and rules ALADI. It was signed on August 12th 1980, and it establishes the following general principles: pluralism, convergence, flexibility, differential treatment and multiplicity (ALADI, 2004).

“ALADI promotes the creation of an area of economic preferences in the region, aiming at a Latin-American common market, through three mechanisms:

- Regional tariff preference granted to products originating in member countries, based on valid tariffs for transfer countries.
- Regional scope agreement among member countries.
- Partial scope agreements, between two or more countries of the area” (ALADI, 2004).

Figure C.5: Latin American Integration Association (ALADI) Map
(Source: ALADI, 2004)

ALADI has brought many benefits and has helped to increase commercial activity between the twelve countries. Figure C.6 shows export and import growth for this zone from 1990 to 2002.

Mexico's most important trade agreements have been signed with the United States and Canada. New trade agreements must be signed with countries in Central and Latin America to promote commerce in the south and southeastern parts of Mexico and improve the efficiency of freight traffic coming to and from North, Central and South America.

Figure C.6: Global Exports and Imports for the ALADI (Latin American Integration Association) (Million USD)

(Source: Created with data from ALADI Statistics, 2003)

This year Mexico was accepted as a member of the Common Market of the South ("Mercado Común del Sur", Mercosur) (El Universal, 2004). Mercosur is a free trade agreement between Bolivia, Chile, Argentina, Brazil and Uruguay. Its objective is commercial integration of these countries through the adoption of a common commercial and customs policy (Mercosur, 2004).

The Plan Puebla Panama is a cooperative trade agreement, of which objective is to integrate commercial activities and improve the quality of life for people living in the Mesoamerican area (Belize, Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, Panama, and Mexico). In Mexico, the states that will

participate the most in this agreement are located in the south and southeast (Yucatan, Quintana Roo, Campeche, Tabasco, Chiapas, Oaxaca, Guerrero, Puebla and Veracruz) (Plan Puebla Panama, 2004). The total number of people living in the Mesoamerican area is 64 million (28 million in the south-southeast Mexico and 36 million in Central America) (Plan Puebla Panama, 2004). They share a common bond through history, culture, traditions and values, as well as similar aspirations and interests.

The goals of Plan Puebla Panama include the integration of road transportation with maritime, air and railroad transportation, as well as the identification of problems and possible solutions to reduce transportation times in this region. This will increase competitiveness in the region resulting in greater commercial activity and integration of the zone.

In 2006 Mexico will be part of the largest free trade agreement in the world, the Libre Comercio de las Americas - ALCA (Free Trade Area of the Americas - FTAA). The FTAA includes 34 countries located between Argentina and Canada, and more than 800 million potential consumers (Free Trade Area of the Americas, 2004)

It is important to mention that 66 percent of the Mexican economy corresponds to exterior commerce; therefore, it is important that Mexico has an adequate transportation infrastructure that can handle these freight volumes.

The numbers for commercial activity between Mexico and the rest of the world in the last ten years are shown in the Tables C.2 and C.3. It is evident that commercial growth (exports and imports in \$US millions) between Mexico and Central and South America is greater than the commercial growth between Mexico and other countries. From 1993 to 2003, imports from North America to Mexico increased by 236 percent, imports from Asia increased by 386 percent, and those from Central and South America increased by 727.85 percent and 300.46 percent respectively. However, the volume of products moved from Central and South America is lower than the volume for countries in North America, Europe and Asia. For example, imports (\$US millions) from Germany to Mexico are equivalent to imports from all of South America to Mexico (2003). Also, exports (\$US million) from Mexico to Canada are greater than exports from Mexico to all of South America (2003).

Table C.2
Total Imports of Mexico in the last ten years (Million of USD)

Country	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
TOTAL	65,366.50	79,345.90	72,453.10	89,468.80	109,808.20	125,373.10	141,974.80	174,457.80	168,396.40	168,678.90	170,958.20
NORTH AMERICA	46,470.00	56,411.20	55,202.80	69,279.70	83,970.30	95,548.60	108,216.20	131,551.00	118,001.60	111,037.00	109,806.60
United States	45,294.70	54,790.50	53,828.50	67,536.10	82,002.20	93,258.40	105,267.30	127,534.40	113,766.80	106,556.70	105,685.90
Canada	1,175.30	1,620.60	1,374.30	1,743.60	1,968.00	2,290.20	2,948.90	4,016.60	4,234.90	4,480.30	4,120.80
ALADI (Latin American Integration Association)	2,172.90	2,599.00	1,420.70	1,755.00	2,306.70	2,589.00	2,857.50	4,017.50	4,743.40	5,473.90	6,528.70
Argentina	252	332.7	190.7	299.6	236.2	263.6	211.7	247.4	441.4	687.3	867.2
Bolivia	16.2	19.1	5.1	8	10.3	7	7.8	13.4	14	23.6	29.4
Brazil	1,200.80	1,225.50	565.3	690	869.3	1,037.80	1,128.90	1,802.90	2,101.30	2,565.00	3,267.50
Colombia	84	121	97.5	97	124.2	151.3	220.4	273.4	344.4	352.4	405.7
Chile	130.1	230.1	154.3	170.8	372.4	552	683.5	893.7	975	1,010.20	1,082.10
Ecuador	37.6	89.5	68.7	62	51.3	70.1	59.9	75.2	110.3	33.1	54.1
Paraguay	5	4.9	2.7	18.2	10.8	1.6	3	1.2	2	1.7	3.7
Peru	169.9	210.9	98.7	116.7	141.6	142.9	180.5	176.7	141.2	152.3	131.2
Uruguay	43.3	56.1	17.4	35.8	35.1	30.8	42.2	83.2	84.6	91.6	101.5
Venezuela	226.9	297.4	214	234	421.2	303.4	297.1	422.4	503.4	532.3	566
Cuba	7.1	11.8	6.2	22.8	34.2	28.4	22.6	28	25.7	24.3	20.3
CENTRE AMERICA	119.2	150.3	88.6	172.2	201.8	221.5	316.6	333.1	359.7	623.5	867.6
Belize	3.4	5.7	2	1.5	2	1.7	1.7	2.2	1.5	1.6	2.8
Costa Rica	21.8	27.6	15.6	57.6	77.4	87.4	191.4	180.1	184.2	416.3	584.2
El Salvador	14.1	19.3	7.9	19	24.1	25.3	18.2	19.8	29.9	36.4	44.3
Guatemala	62.1	83.5	51.1	76.8	80.5	81.3	82.6	90.8	95.2	116.7	151.1
Honduras	6.3	3.6	3.6	5.1	6.4	12.1	8	13.3	17.4	25.4	47
Nicaragua	11.4	10.7	8.4	12.2	11.4	13.6	14.8	26.9	31.4	27.1	38.1
EUROPE UNION	7,798.70	9,058.20	6,732.20	7,740.60	9,917.30	11,699.30	12,742.80	14,775.10	16,165.50	16,441.60	17,861.90
Germany	2,852.40	3,100.90	2,687.10	3,173.70	3,902.30	4,543.40	5,032.10	5,758.40	6,079.60	6,065.80	6,274.90
Austria	105.8	121	87.5	113.1	139.4	191.8	170.1	176.8	219.6	186.6	254.8
Belgium	275	336.5	210	238.8	327.3	355.4	305.2	465.6	630.5	556.9	573
Denmark	130.1	130.9	70.9	70.7	96.4	119.6	126.5	142	169.2	177.4	198.8
Spain	1,155.30	1,338.30	694.1	629.5	977.7	1,257.00	1,321.80	1,430.00	1,827.40	2,223.90	2,288.30
Finland	50.1	66.1	63.5	84.6	100.6	122	175.8	211.7	249.5	150.9	277
France	1,105.20	1,526.90	979.2	1,019.00	1,182.40	1,429.90	1,393.70	1,466.60	1,577.00	1,806.80	2,015.80
Greece	22.8	23.7	10.3	9.7	17.2	6.5	15.9	29.8	22.7	29.4	22.9
Holand	241.6	240.1	217.9	225.1	261.9	328.4	325.6	363.1	470.9	546.6	555.7
Ireland	151.3	137.7	181.1	239.1	265.9	308.5	329.7	403.6	550.9	614.4	794.6
Italy	834.9	1,021.40	771.5	999.1	1,326.00	1,581.10	1,649.40	1,849.40	2,100.30	2,171.10	2,474.20
Luxemburg	3.7	10.2	8	8.5	16.4	16.6	10	17.3	17	17	29.9
Portugal	12.2	20.7	18.8	21.5	34.1	43.8	52.2	51.4	100.7	94.3	126.5
United Kingdom	593	706.6	531.8	679.4	915.3	1,056.20	1,135.20	1,091.30	1,344.00	1,349.80	1,242.30
Swedish	265.3	277.1	200.7	228.8	354.3	339.2	699.6	1,318.00	806.1	450.9	733.2
FREE TRADE EUROPE ASSOCIATION	530.7	530.4	414.3	484.2	616.8	648.3	777	851.1	906.9	872.1	921.2
Iceland	0.1	0.1	0.9	0.6	2	1.4	0.9	0.4	1.7	0.7	5.6
Norway	33.2	40	24.7	27	55.9	58.2	55.7	98	142.5	93.2	96
Switzerland	497.3	490.3	388.7	456.6	558.9	588.7	720.4	752.7	762.7	778.3	819.6
NIC'S	2,201.60	2,815.00	2,139.00	2,580.60	3,582.60	4,187.00	5,313.80	6,911.30	8,235.90	10,261.60	8,500.90
Korea	925.8	1,208.80	974.2	1,177.60	1,831.00	1,951.30	2,964.00	3,854.80	3,631.60	3,947.60	4,137.40
Taiwan	717.4	1,029.40	716.2	890.9	1,136.50	1,526.60	1,556.80	1,994.30	3,015.30	4,250.10	2,509.10
Hong Kong	343.2	286.9	159.4	129.2	189.4	216.1	252.8	455.8	441.8	509	516.6
Singapur	215.1	290	289.2	382.9	425.6	493	540.1	606.3	1,147.20	1,555.00	1,337.80
JAPAN	3,928.70	4,780.00	3,952.10	4,132.10	4,333.60	4,537.00	5,083.10	6,465.70	8,085.70	9,348.60	7,622.80
PANAMA	60.7	24.5	8.9	6.6	19.2	16	25.6	119.6	45.2	35.3	37.8
CHINA	386.4	499.7	520.6	759.7	1,247.40	1,616.50	1,921.10	2,879.60	4,027.30	6,274.40	9,400.80
ISRAEL	45.3	85.1	46.7	79.1	112.1	137.4	172.7	296.5	257.7	250.1	313.5
REST OF THE WORLD	1,652.30	2,392.60	1,927.30	2,479.10	3,500.50	4,172.40	4,548.40	6,257.40	7,567.60	8,060.70	9,096.40

Source: Ministry of Economy Mexico, 2004

Table C.3
Total Exports of Mexico in the last ten years (Million of USD)

Country	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
TOTAL	51,832.00	60,817.20	79,540.60	96,003.70	110,236.80	117,459.60	136,391.10	166,454.80	158,442.90	160,762.70	165,355.20
NORTH AMERICA	44,419.50	53,127.90	68,260.10	82,746.00	96,340.90	104,442.90	122,784.20	151,038.60	143,366.00	145,854.00	149,634.50
United States	42,850.90	51,645.10	66,272.70	80,574.00	94,184.80	102,923.90	120,392.90	147,685.50	140,296.50	143,047.90	146,802.70
Canada	1,568.70	1,482.80	1,987.40	2,172.00	2,156.10	1,518.90	2,391.30	3,353.10	3,069.50	2,806.00	2,831.80
ALADI (Latin American Integration Association)	1,697.10	1,772.60	3,247.80	3,788.00	4,022.60	3,242.60	2,387.10	2,890.20	3,026.90	2,609.60	2,394.10
Argentina	282.9	247.7	312.9	519.8	497.6	384.5	256.1	288.7	243.7	111.7	191.7
Bolivia	17.1	13.4	24.1	30.4	31.6	34.6	31.6	26.6	24.5	20.3	23.9
Brazil	292.2	376.1	800.2	878.6	703	535.5	399.4	517.2	585	480.9	418.9
Colombia	238.8	306	453.5	438.2	513.3	449.1	367.6	461.8	506.3	555.7	520.2
Chile	199.7	204.4	489.8	688.7	842.3	625	366.4	431.4	374.4	258.6	322.7
Ecuador	56.5	109.8	116	120.9	143	123.2	68.9	108	127.8	151.3	129.3
Paraguay	12.6	10.5	21.6	30.2	23.8	14.8	8.5	9.9	12.5	9	8.4
Peru	94.2	110.4	178.9	211.4	238.4	195.6	178.1	210	172.7	195.6	166.2
Uruguay	179.5	46.8	76.7	115.6	69.1	83.8	59.9	108	107	110.1	141.6
Venezuela	228	173.8	379.6	423.6	675	546.1	436.2	519.5	697.5	586.4	329
Cuba	95.5	173.8	394.5	330.7	285.4	250.4	214.4	209.2	175.6	130	142.4
CENTRE AMERICA	502.3	560.2	721.9	889	1,147.00	1,321.10	1,296.90	1,410.90	1,480.10	1,484.00	1,504.40
Belize	26.8	27.4	22.3	33.2	33	37.7	37.9	46.8	36	62.2	54.6
Costa Rica	99.6	94.6	141.9	188.1	221.2	282.1	250.5	286.2	338.2	344	331.5
El Salvador	113	128.5	147.7	158.1	214.2	218	244.4	245.6	274.3	265	261.2
Guatemala	203.8	218.3	310.2	360.2	498.4	591.1	543.6	535.2	559.7	513.9	536.8
Honduras	38.5	70	68.7	96.9	116	134.6	156.1	203.8	180.4	207.8	209.2
Nicaragua	20.7	21.3	31.1	52.6	64.2	57.5	64.5	93.4	91.7	91	111.1
EUROPE UNION	2,788.60	2,805.90	3,353.50	3,509.80	3,987.60	3,889.20	5,202.70	5,610.10	5,332.60	5,214.50	5,591.70
Germany	430.4	394.7	515.4	640.9	718.7	1,151.60	2,093.10	1,543.90	1,504.10	1,236.30	1,753.00
Austria	43.7	10.1	12.8	10	15.8	10.5	10.8	17	19.6	15.4	10.2
Belgium	226	270.8	486.5	408.6	372.7	230.4	240.7	227	317.8	295.8	137.3
Denmark	17.9	21.6	7.6	18.6	30.6	35.5	49.1	44.7	44.4	37.8	38.9
Spain	917.7	857.9	796.9	906.9	939	713.5	822.4	1,519.80	1,253.90	1,431.00	1,464.40
Finland	1.5	4.6	1.9	1.5	5.1	1.7	8.2	4.3	8.5	10.7	9.4
France	456.2	517.8	483.5	425.9	429.9	401.4	288.8	374.6	372.6	349.2	322.4
Greece	5.6	5	8.4	8.9	10.7	9.4	7.5	10	7.1	6.7	9
Holand	193.2	174.4	177.1	191.8	261.7	338.7	487.7	439	508.1	630.1	594.9
Ireland	121	111.6	70.5	146.1	113	37.1	67	112.2	186.4	186.9	167.7
Italy	84.3	86.1	197.3	139.9	273.4	181.4	170.3	222	239.7	173.7	267.2
Luxemburg	0.1	0.3	2.9	2.6	2.7	6.2	5.9	8	11.7	38.6	41.4
Portugal	72.4	60	81.4	56.8	97.3	87.2	180.4	194.3	148.7	133.1	183.4
United Kingdom	201.7	267.3	481	531.9	664.2	639	747	869.8	672.9	625	561.2
Swedish	16.8	23.9	30.4	19.6	52.8	45.5	23.7	23.5	37.2	44.2	31.3
FREE TRADE EUROPE ASSOCIATION	151.7	169.7	624.9	399.2	358.5	275.6	456	586.1	456.8	461	706.6
Islandia	0.9	0.3	0.4	0.4	1	0.7	0.9	0.6	0.4	0.2	0.2
Norway	9.8	11.9	16.3	38.3	13.5	17.4	10.5	32.7	5.6	7.2	8.4
Switzerland	140.9	157.5	608.1	360.5	343.9	257.6	444.6	552.8	450.7	453.7	698
NIC'S	277.3	305.2	813	907.9	781.4	789.9	902.5	718.2	843.7	912.5	646.7
Korea	28.3	41.3	91.2	197.6	68.3	73.5	153.8	188.9	309.8	205.8	100.5
Taiwan	23.4	23.1	44	41.6	42.7	49.9	91.2	143.6	171.9	214.1	105.6
Hong Kong	94.6	173.5	504.3	433.6	283.1	217.1	177.8	187.3	119.8	194.6	257.9
Singapur	131.1	67.3	173.5	235.1	387.2	449.4	479.6	196.4	242.2	298	182.7
JAPAN	686.4	997	979.3	1,393.40	1,156.30	851.3	776.1	930.5	620.6	465.1	605.8
PANAMA	147.1	123.7	224.1	280.7	334.3	351.1	303.4	282.8	247.1	316	355.6
CHINA	44.8	42.2	37	38.3	45.9	106	126.3	203.6	281.8	455.9	463
ISRAEL	103.8	3.4	10.5	9.5	30.4	17.9	37.9	54.6	39.4	51.2	56.6
REST OF THE WORLD	1,013.30	909.3	1,268.40	2,041.80	2,032.00	2,172.00	2,118.10	2,731.30	2,747.90	2,939.00	3,396.20

Source: Ministry of Economy Mexico, 2004

C.2 Freight Distribution

In 2001 Mexico transported 732.8 million tons of products. The distribution of this merchandise by mode of transportation is described in the figure below.

MODE	FREIGHT MOVED	
	TONS (millions)	(%)
Truck	413.2	56.2
Railroad	78.1	10
Maritime	241.1	32.9
Air	0.4	0.9
TOTAL	732.8	100

Figure C.7: Freight movement by mode of transportation (2001)

Source: Ministry of Communications and Transports Mexico, 2003

According to the information provided by the online magazine Transporte Siglo XXI, 57.55 percent of the total freight is moved by truck, 31.93 percent

by vessels, 10.47 percent by railroad and 0.06 percent by airplanes (Transporte siglo XXI, 2004).

The following section will explain freight movement by mode of transportation, including product types, volumes and origin-destination.

C.3 Freight Flows

C.3.1 Road Transportation

According to the volume of products moved each year, road transportation is the most important mode of transportation in Mexico. Figure C.8 shows the volumes moved by truck transportation from 1991 to 2001. Table C.4 shows the volumes moved, daily flow of vehicles, and the value of products moved along the main highway network in Mexico. Figure C.9 shows that the volume (tons) of industrial products moved by road transportation in Mexico represents the 45.3 percent of all products, therefore this is the most important product moved in the country.

Figure C.8: Freight volume transported by trucks from 1991 to 2001 (tons/day)

Source: Created with data from the Ministry of Communications and Transports, 2002

Table C.4

Daily trucks flow, tons and freight value (millions USD) for road transportation

Products	Trucks	Tons	%	Value (USD/day)
Forest	1,447	24,073	1.88%	25,627
Agricultural	14,348	212,366	16.56%	128,972
Animals	6,060	73,569	5.74%	131,622
Minerals	2,577	64,949	5.07%	230,444
Petroleum	4,221	102,981	8.03%	123,709
Inorganics	4,205	79,370	6.19%	138,076
Industrial	40,215	580,861	45.30%	1,277,366
Others	13,063	144,022	11.23%	254,722
Empty	41,637	0	0.00%	0
Total	127,773	1,282,191	100.00%	2,310,538

Source: Centeno et al., 2003.

Figure C.9: Products moved by road transportation in Mexico (tons/day)

(Source: Centeno, et al., 2003.)

The main origins for products moved by road transportation in Mexico are shown in Table C.5. Notice that the most important origins are Mexico City, Monterrey and Nuevo Laredo. Nuevo Laredo is located at the northern part of the country and it is the most important border crossing for freight transportation with the United States. The product volume (ton/day) moved in these cities is: 150 248, 65 785 and 52 072 tons/day respectively (Rico et al., 1998). The most important destinations for products moved by road transportation are Mexico City and Guadalajara, with a volume (ton/day) of 226 439 and 70 152 tons/day respectively (Rico et al., 1998). (Refer to Table C.6).

Table C.5
Main Origins of Mexican Road Transportation

Centroid	Tonnage (ton/day)	# of Trucks/Day	Freight Value (Millions USD/Day)
México D.F.	150,248	16,165	313.3
Monterrey, N.L.	65,785	4,519	116.1
Guadalajara, Jal.	64,999	5,719	85.8
Nuevo Laredo, Tamps	52,072	3,546	224.8
Torreón, Coah.	33,042	1,402	28.5
Veracruz, Ver	28,183	1,787	87.5
Puebla, Pue.	26,241	2,993	72.5
Coatzacoalcos, Ver.	20,750	1,202	29.1
San Luis Potosí, S.L.P	20,223	1,632	36.4
Matamoros, Tamps.	19,696	1,146	32.3
Tampico, Tamps.	19,691	1,247	36.1
Chihuahua, Chih.	19,350	1,520	26.4
Hermosillo, Son.	18,319	2,326	24.7
Cd. Juárez, Chih.	16,973	1,471	26.3
Gómez Palacio, Dgo.	14,897	621	21.8
Toluca, Mex.	14,894	2,415	31.4
Querétaro, Qro.	14,453	1,414	27.1
Minatitlán, Ver.	14,057	669	18.3
Tijuana, B.C.N	10,544	1,678	20.4
Durango, Dgo.	10,178	805	13.9
Aguascalientes, Ags.	10,033	1,126	30.6
Morelia, Mich.	10,009	1,684	12.4
Cd. Madero, Tamps.	9,277	260	11.4
Villahermosa, Tab.	8,630	1,045	11.9
Salamanca, Gto.	8,499	393	11.7
Saltillo, Coah.	8,295	462	15.3
Cadereyta, N.L.	8,279	288	10.7
Reynosa, Tamps.	7,873	958	15.6
León, Gto.	7,531	900	24.4
Zacatecas, Zac.	7,527	959	10.2
Manzanillo, Col.	7,219	540	19.5
Monclova, Coah.	7,154	260	11.4
Celaya, Gto.	6,349	666	11.4
Cuernavaca, Mor.	1,951	236	10.6

Source: Rico et al., 1998.

Table C.6
Main destinations of Mexican Road Transportation

Centroid	Tonnage (ton/day)	# of Trucks/Day	Freight Value (Millions USD/Day)
México D.F.	226,439	16,521	496.8
Guadalajara, Jal.	70,152	5,852	117.1
Monterrey, N.L.	55,012	4,512	96.3
San Luis Potosí, S.L.P.	26,465	1,637	42
Puebla, Pue.	25,753	2,581	61.1
Villahermosa, Tab.	23,144	1,470	36.9
Nuevo Laredo, Tamps	22,388	2,441	62.9
Chihuahua, Chih.	20,783	1,625	29.9
Torreón, Coah.	20,027	1,481	30.5
Toluca, Mex.	19,733	2,461	51.8
Aguascalientes, Ags.	18,274	1,136	32.4
Veracruz, Ver.	18,205	2,158	46.6
Cd. Juárez, Chih.	18,101	1,542	26.7
Querétaro, Qro.	17,619	1,587	32.7
Tijuana, B.C.N	16,112	1,707	20.8
Hermosillo, Son.	15,821	2,480	27
Tampico, Tamps.	15,113	1,281	25.6
Reynosa, Tamps.	15,034	924	23.1
Oaxaca, Oax.	14,852	1,874	18
León, Gto.	14,340	1,044	22.6
Durango, Dgo.	14,334	805	18.2
Matamoros, Tamps.	14,207	986	23.3
Coatzacoalcos, Ver.	13,393	1,257	16.7
Morelia, Mich.	11,823	1,810	14.1
Zacatecas, Zac.	10,583	977	11.1
Orizaba, Ver.	9,934	697	11.2
Culiacán, Sin.	9,267	611	13.8
Mérida, Yuc.	8,574	497	14.1
Celaya, Gto.	7,839	687	14
Manzanillo, Col.	6,467	581	14.1
Saltillo, Coah.	6,245	459	14.4
Altamira, Tamps.	3,225	163	11.1

Source: Source: Rico et al., 1998.

C.3.2 Railroad Transportation

Currently, railroad transportation in Mexico moves 17 percent of the total terrestrial transportation (Transporte Siglo XXI, 2004). This is an increase of five percent from 1996. "This growth started in 1996 with railroad privatization, and current railroad transportation is a real competitor for road transportation" (Corso, 2004).

Figure C.10 shows the history of products moved by railroad in Mexico for the period 1992 to 2002. Note that in terms of road transportation, industrial and agricultural products are the most important products moved by the railroad in Mexico. It is also evident that the volume of products moved by rail started to grow in the middle of the 1990's, just when the privatization took place. Figure C.11 shows a detailed list of products moved by rail (tons) for the year 2001.

Table C.7 shows the main origins of Mexican railroad transportation and Table C.8 shows the main destinations of Mexican railroad transportation. Notice that Nuevo Laredo, the main border crossing for freight transportation with the United States is also the most important origin for railroad transportation with 19 486 tons/day and 300 railroad cars at day. Mexico City is the main destination with 14 305 tons/day and 238 railroad cars every day.

Figure C.10: Evolution of products moved by railroad in Mexico
 (Source: Created with data from the Ministry of Communications and Transports Mexico, 2003)

Figure C.11: Main products moved by railroad in Mexico (2001)
 (Source: Created with data from the Mexican Institute of Transportation, 2002)

The products shown in Figure C.11 represent the 67 percent of all products moved by rail. The other 33 percent correspond to other various products.

Table C.7
Main origins of Mexican Railroad Transportation

Centroid	Tonnage (ton/day)	# of Cars/Day	Freight Value (Millions USD/Day)
Nuevo Laredo, Tamps	19,486.48	300	20.77
Manzanillo, Col.	6,144.04	92	2.657
Salinas Victoria, N.L.	5,995.29	82	6.886
Veracruz, Ver.	5,923.39	96	2.388
Cd. Juárez, Chih.	4,442.83	64	3.066
Matamoros, Tamps.	3,797.78	56	2.595
Palau, Coah.	3,199.04	43	3.736
Piedras Negras, Coah.	2,680.03	56	9.107
México D.F.	2,185.06	56	2.723
Nogales, Son.	1,805.92	25	16.681
Hermosillo, Son.	1,600.50	39	7.136
Toluca, Mex.	1,216.22	54	13.183
Saltillo, Coah.	1,075.93	45	11.007
Chiautempan, Tlax.	296.27	10	2.429

Source: Rico et al., 1998.

Table C.8
Main destinations of Mexican Railroad Transportation

Centroid	Tonnage (ton/day)	# of Cars/Day	Freight Value (Millions USD/Day)
México D.F.	14,305.31	238	11.154
Guadalajara, Jal.	10,624.35	172	3.887
Monterrey, N.L.	7,854.49	117	3.588
Monclova, Coah.	7,362.19	103	6.973
Nuevo Laredo, Tamps	3,713.98	125	23.064
Cuautitlan, Mex.	2,590.22	42	4.45
Torreon, Coah.	2,083.22	33	1.839
Piedras Negras, Coah.	1,981.73	64	10.044
Delicias, Chih.	1,853.49	25	2.025
Nogales, Son.	1,833.87	51	7.295
Cd. Juárez, Chih.	1,819.23	28	1.788
Hermosillo, Son.	1,630.71	25	16.637
Toluca, Mex.	1,570.65	34	5.478
Saltillo, Coah.	1,497.68	38	6.725

Source: Rico et al., 1998.

C.3.3 Air Transportation

The shipment of products by air has been increasing very slowly due to the lack of appropriate infrastructure. However, some airports are starting to build new cargo terminals, and this is increasing the air cargo volume moved in the country. According to cargo statistics, air transportation moves 0.6 percent of the total freight moved in Mexico. Figure C.12 shows the tons moved by air transportation in Mexico from 1990 to 2002, and Figure C.13 shows the tons moved by air transportation from 1995 to 2000 for domestic and international markets. Notice the importance of air cargo in Mexico for international markets (more than 70 percent), and the reduced participation for domestic markets.

Figure C.12: Air Cargo moved in Mexico from 1990 to 2002

(Source: Reyes, 2000.)

Air cargo growth between 1990 and 1995 was 87 percent, and between 1995 and 2000 it was 67 percent. This means an increase of 117 500 tons in the 1990 – 1995 period, and 170 055 tons in the 1995 – 2000 period.

Figure C.13: Air Cargo distribution in Mexico (thousand of tons)

(Source: Reyes, 2000)

The following figure shows the main airports in Mexico according to freight volume moved from 1990 to 2000. Notice that Mexico City's international airport is the most important airport in the country, and it moves five times the volume moved by Tijuana's International Airport, the second most important airport in Mexico.

Figure C.14: Cargo volume of main Mexican Airports (1990-2000)

(Source: Created with data from the Mexican Transportation Institute, 2001)

Table C.9 shows the main origin-destination pairs for domestic air cargo transportation in Mexico. The cargo is presented according to origin cargo volumes, destination cargo volumes, and the sum of both cargo volumes. Notice that in many cases Mexico D.F. (Mexico City) appears as the origin or destination. This is clear evidence of a centralized economy in Mexico City, and the lack of transportation infrastructure connecting other cities in order to bypass Mexico City. This means that some freight moved in the country has to pass by Mexico City, increasing transportation times, pollution and diesel fuel consumption affecting the country's economy.

Table C.9
Main origin – destination pairs for air cargo transportation in Mexico.

Origin - Destination	One Way (origin) (tons)	One way (return) (tons)	Total
1. GUADALAJARA, JAL.-MEXICO, D.F.	3,476	5,921	9,397
2. MEXICO, D.F.-TIJUANA, B.C.	5,506	3,392	8,898
3. MEXICO, D.F.-MONTERREY, N.L.	4,408	4,015	8,423
4. MERIDA, YUC.-MEXICO, D.F.	2,274	3,277	5,551
5. CANCUN, Q.R.-MEXICO, D.F.	889	4,395	5,284
6. MEXICO, D.F.-VILLAHERMOSA, TAB.	2,425	737	3,162
7. GUADALAJARA, JAL.-TIJUANA, B.C.	1,318	1,096	2,414
8. MEXICALI, B.C.-MEXICO, D.F.	506	1,591	2,097
9. MEXICO, D.F.-VERACRUZ, VER.	1,776	277	2,053
10. HERMOSILLO, SON.-MEXICO, D.F.	645	1,387	2,032
11. MEXICO, D.F.-PUERTO VALLARTA, JAL.	1,509	297	1,806
12. MEXICO, D.F.-TUXTLA GUTIERREZ, CHIS.	1,387	341	1,728
13. ACAPULCO, GRO.-MEXICO, D.F.	227	1,451	1,678
14. CIUDAD JUAREZ, CHI.-MEXICO, D.F.	606	1,062	1,668
15. MEXICO, D.F.-OAXACA, OAX.	989	646	1,635
16. CHIHUAHUA, CHI.-MEXICO, D.F.	499	1,058	1,557
17. MEXICO, D.F.-SAN JOSE DEL CABO, B.C.S.	1,269	134	1,403
18. MEXICO, D.F.-TAPACHULA, CHIS.	735	570	1,305
19. CULIACAN, SIN.-MEXICO, D.F.	336	865	1,201
20. LA PAZ, B.C.S.-MEXICO, D.F.	383	719	1,102
Total (top 20 origin - destinations)	30,780	32,512	63,292
Other Origins - Destinations	21,405	19,673	38,242
Total	52,185	52,185	101,534

Source: Mexican Transportation Institute, 2003

C.3.4 Maritime Transportation

Mexico has the third longest coast in America (11 122 km), after the United States and Canada. Maritime transportation in Mexico moves 32 percent of the total domestic freight and 80 percent of international freight (Ministry of Communications and Transports, 2003). According to statistics, in 1985 domestic maritime transportation moved 1 341 748 tons, and in 2000 it

moved 513 577 tons. This represents a reduction of 62 percent in 15 years (Enriquez, 2002). As a result of this reduction, Mexico's rank in terms of volume moved by maritime transportation dropped from 44th in 1998 to 62nd in 1999 (Enriquez, 2002). On the other hand, international maritime transportation grew more than 500 percent from 1985 to 2000 (Enriquez, 2002). This increase was a result of the General Agreement on Tariffs and Trade (GATT) between Mexico and United States signed in 1985.

Figure C.15 shows the main products moved by maritime transportation in Mexico from 1992 to 2002 (including the domestic and international markets).

Figure C.15: Main products moved by maritime transportation in Mexico from 1992 to 2002

(Source: Created with data from the Ministry of Communications and Transports, 2003)

Petroleum and hydrocarbons are the most important products for maritime transportation in Mexico as a result of the remarkable growth that started with the petroleum boom in the 1970's. They represent 55 percent of the total products moved by maritime transportation in Mexico. Statistics show that 8.5 million tons of petroleum and hydrocarbons were transported by maritime transportation in 1970, and 36 million tons were moved in 2000 (only for the domestic market) (Mexican Transportation Institute, 2003). This represents an increase of almost 400 percent in thirty years.

Sixty eight percent of the total maritime transportation in Mexico is moved through ports located in the Pacific coast, and the other 32 percent is moved through ports located in the Gulf of Mexico. Figure C.16 shows the volumes moved (international and domestic) by the main ports located in the Pacific Coast from 1990 to 2000, and Figure C.17 shows the same information for the main ports located in the Gulf of Mexico (petroleum and hydrocarbon numbers are not included in Figures C.16 and C.17). Due to the importance of petroleum and hydrocarbons in Mexico, Figure C.18 shows the statistics for these products moved by the main ports in Mexico.

Figure C.16: Volume of products transported by the main ports located in the Pacific coast

(Source: Created with data from the Ministry of Communications and Transports Mexico, 2001)

Figure C.17: Volume of products transported by main ports located in the Gulf of Mexico

(Source: Created with data from the Ministry of Communications and Transports Mexico, 2001)

Figure C.18: Main ports in Mexico according to the petroleum and hydrocarbons volume transported

(Source: Created with data from the Ministry of Communications and Transports Mexico, 2001)

C.4 Intermodal/Multimodal Transportation

C.4.1 Containers movement

In 1999 and 2000, intermodal terminals in Mexico moved an annual average of 37 645 containers per terminal. The port terminals moved the higher volume with an annual average of 70 620 containers per terminal, followed by the terrestrial terminals with an annual average of 20 058 containers per terminal. The private terminals dedicated to the transportation of automobile parts moved an annual average of 12 314 containers per terminal, public terminals moved an annual average of 25 221 containers per terminal, and

empty container deposits moved an annual average of 21 464 containers per deposit.

Figure C.19 shows the number of containers moved by the railroad in Mexico from 1996 to 2001. The number of containers is classified by Railroad Company. Notice the important growth that intermodal transportation is experiencing just a few years after its privatization in 1997 and 1998. The most important railroad companies in Mexico are TFM and Ferromex. They are reporting important achievements and actions toward intermodal transportation like the construction of new terminals and new intermodal services at maritime ports and between railroads from United States and Canada.

Figure C.19: Containers moved by railroad in Mexico

(Source: Created with data from the Ministry of Communications and Transports Mexico, 2002)

The intermodal terminals that had the highest movement of containers in 2000 were ICAVE-Veracruz port terminal with a volume of 276 000 containers and SID-Querétaro terminal with a volume of 92 000 containers. Multimodal terminals had an annual average volume of 729 991 tons, and according to the type of terminals the numbers were 891 982 tons per year for port terminals and 568 000 tons per year for terrestrial terminals.

Figure C.20 shows the number of containers (TEU'S) moved in the main maritime ports in Mexico from 1996 to 2002.

Figure C.20: Containers movement in main maritime ports in Mexico

(Source: Created with data from the Ministry of Communications and Transports Mexico, 2003)

C.4.2 Products transported by Intermodal and Multimodal Transportation

The most common products moved in containers in Mexico are: small and major appliances, electronics, small supplies for electronic products, automobile parts, fabrics, clothes, footwear, paper, chemicals, beer, tequila, milk, fruit, shellfish, crackers, rice, beans, flour, orange juice, honey, salt, sugar, coffee beans, aluminium containers, soaps, toothpaste, shampoo, crafts and furniture (Guadalupe et al., 2003).

The most common products moved by multimodal transportation (not using containers) are: minerals for steel production, steel, bulk plastic, agricultural bulk (corn, wheat, soy) and fine woods (Guadalupe et al., 2003).

C.4.3 Intermodal transportation users

It is important to mention that intermodal transportation in Mexico is used only for international markets (imports only). Domestic users in the country are not currently using containers to move their products (export or domestic transportation). In fact all containers returning to their place of origin are empty and these containers are not permitted to be used in Mexico for domestic or for export purposes.

The most common users of public intermodal terminals are:

1. - Liner shipping companies: APL, Hanjin, TMM Lines, Lykes Lines, Maersk Sealand, P&O, Hapag Lloyd, Tecomar, Ivaran, Contship, Cagema Line, Ned Lloyd, Deppe Lines, Evergreen, Gran Colombiana, Columbus, Zim Line, Trans Roll, Alianca, Italian Line, Coral Line, Sudamericana de Vapores, Nipon.

2. - Main logistics operators: Pacer Stacktrain.

3. - Others companies: Xerox, Kimberly Clark, Sony, LG, Samsung, Daewood, Petrocel, Celanese, Arancia, Modelo Brewer, Corona Soap, and Shellfish.

The most common users of private intermodal terminals are:

1. - Liner shipping companies: American President Lines (APL) and Pacer Stacktrain.

2. - Automobile companies: General Motors (Mexico and USA), Nissan, Daimler Chrysler and Honda.

3. - Others companies: Xerox y Unipress.

C.5 Commercial Corridors

Multimodal and intermodal corridors are defined according to the freight volumes, type of products, origin – destination, industrial areas, commercial trades and transportation infrastructure. There are specific corridors for each mode of transportation and there are commercial corridors that include all modes of transportation. There is also another classification for corridors:

intermodal and multimodal corridors. Intermodal corridors are used only for products consolidated in containers between two or more modes of transportation. Multimodal corridors are used for different products that must be moved in different quantities by various modes of transportation in order to reach their final destination.

According to the classifications and the characteristics mentioned above, there are many corridors identified in Mexico. Rico et al. (1998) identified the major corridors for railroad and highway transportation in the country. The User Equilibrium Model assumes that vehicles select their routes at their particular discretion. Rico et al. employed this model when identifying highway corridors through an analysis of origin destination flows for assigning the truck freight origin - destination matrix to the highway network (Rico et al., 1998). For railroad corridors, it was assumed that the National Mexican Railroads Company (which was once operated by the government) assigned its flows to the different routes seeking to minimize the total cost of moving its full freight demand among the different origin destination pairs. These major highway and railroad corridors are listed in Table C.10 and Table C.11 respectively.

Table C.10
Major Road Corridors Ranking

Corridor	Length (km)	Traffic (Trucks/day)	Tonnage (ton/day)	Ranking
México - Querétaro	212	6,400	85,000	1
Querétaro - Nuevo Laredo (through S.L.Potosí and Monterrey)	1,058	3,500	50,200	2
México - Veracruz (through Jalapa)	446	3,460	33,200	3
Guadalajara - Monterrey (through Zacatecas and Saltillo)	734	2,760	43,500	4
San Luis Potosí - Cd Juárez (through Zacatecas and Torreon)	1,348	2,470	38,200	5
México - Campeche (through Puebla and Minatitlan)	1,447	2,800	25,000	6
Irapuato - Zacatecas (through León and Aguascalientes)	285	2,700	24,000	7
Querétaro - Guadalajara (through Irapuato and La Piedad)	380	1,900	19,900	8
México - Tampico (through Poza Rica and Tuxpan)	522	2,100	21,000	9
Rynosa - Durango (through Monterrey and Torreón)	843	2,000	32,000	10
México - Guadalajara (through Toluca and Morelia)	624	3,000	30,200	11
Guadalajara - Nogales / Tijuana	2,303	1,470	21,000	12
México - Monterrey (through Pachuca and Cd. Victoria)	1,010	1,670	19,300	13
Reynosa/Matamoros - Tampico (through Cd. Victoria)	565	1,070	12,700	14
Guadalajara - Tampico (through Aguascalientes and S.L. Potosí)	806	1,330	14,300	15
Guadalajara - Manzanillo (through Colima)	306	1,580	10,500	16
Puebla - Oaxaca (through Huajuapán de León)	419	2,100	11,600	17

Source: Rico et al., 1998.

Table C.11
Major Railroad Corridors Ranking

Corridor	Length (km)	Tonnage (ton/day)	Freight Value (millions USD/day)	Ranking
México - Nuevo Laredo (through Querétaro, Saltillo and Monterrey)	1,188	22,300	25.29	1
Saltillo - Piedras Negras (through Mondova)	440	7,900	16.51	2
San Luis de la Paz - Acámbaro (through Celaya)	168	10,400	9.20	3
México - Acámbaro (through Toluca)	293	3,450	6.69	4
Querétaro - Nogales (through Irapuato, Guadalajara, Tepic and Hermosillo)	2,240	9,600	5.85	5
Tula - Coatzacoalcos (through Pachuca, Orizaba and Tuxtepec)	759	13,900	5.64	6
Irapuato - Cd. Juárez (through Zacatecas, Torreón and Chihuahua)	1,618	5,200	5.64	7
México - Puebla (through Irolo)	202	5,900	4.81	8
Guadalajara - Manzanillo (through Colima)	352	10,200	4.60	9
Tampico - Aguascalientes (through San Luis Potosí)	673	4,400	4.60	10
Matamoros - Torreón (through Monterrey)	718	3,800	3.97	11
Acámbaro - L. Cárdenas (through Morelia and Uruapan)	514	3,350	3.76	12

Source: Rico et al., 1998.

The corridors mentioned above are not the only corridors identified in Mexico. According to the Ministry of Communications and Transports the main multimodal corridors in Mexico are:

- Pantaco (Mexico City) -Nuevo Laredo
- Nogales –Hermosillo
- Puertos Asiáticos -Manzanillo -Pantaco (Mexico City)
- Manzanillo –Guadalajara
- Veracruz –Manzanillo
- Coatzacoalcos –Salina Cruz –Asian Ports
- Asian Ports –Manzanillo –Nuevo Laredo

- Monterrey –Tampico –Progreso
- Cd. Juárez -Pantaco (Mexico City)
- Lázaro Cárdenas -Pantaco (Mexico City)
- Nogales –Guadalajara –Pantaco (Mexico City)
- Altamira –San Luis Potosí –Querétaro
- Nuevo Laredo –San Luis Potosí
- Piedras Negras –Veracruz
- Mexico City –Europe (Mediterranean)
- Lázaro Cárdenas –Nuevo Laredo
- Lázaro Cárdenas –Cd. Juárez
- Altamira -Europe (Mediterráneo) (Ministry of Communications and Transports, 2003)

These corridors are shown in Figure C.21. Notice that the most important corridors connect Mexico City, Guadalajara and Monterrey.

Figure C.21: Multimodal Corridors in Mexico
(Source: Ministry of Communications and Transports Mexico, 2003)

Figure C.22: Major Road Corridors in Mexico
(Source: Ministry of Communications and Transports Mexico, 2003)

According to a document published by the Ministry of Communications and Transports the main road corridors in Mexico are shown in Figure C.22.

Notice that almost all corridors cover the entire country. However, some actions are used in order to improve commerce and movement on these corridors by connecting them with the most important borders and corridors in North and South America. According to information from the Ministry of Communications and Transports, the corridors mentioned above and their most important connections are shown in the following figure.

Figure C.23: Mexican Corridors connecting with North and South America Corridors

(Source: Ministry of Communications and Transports Mexico, 2003)

It can be observed that there are many connections between Mexico and North America, and that there is only one connection between Mexico and South America. This does not mean that commerce with Central and South America does not exist. It indicates a lack of commercial interests in the last few decades between Mexico, Central and South America, and the main interest of Mexico to promote commercial trade with its current most important commercial partners, United States and Canada. This low commercial activity with Central and South America resulted in the low development of transportation infrastructure in southern Mexico. Conversely, the transportation infrastructure of northern Mexico had many important improvements.

During recent years, Mexico acknowledged the potential benefits of trade with Central and South America. It has already signed some trade agreements with countries of Central and South America, and it is still in the process of negotiating various others (some of these trade agreements were described in the part C.1 of this chapter). These trade agreements will increase the commercial activity between Mexico, Central America and South America; however, important improvements in transportation infrastructure need to be achieved in order to support this increased commercial activity.

As an example of these new improvements and as part of the Plan Puebla Panama, the Ministry of Communications and Transports has proposed a possible extension for Mexican corridors in order to improve commercial

activity in southern Mexico and prepare future improvements for transportation infrastructure in these corridors (refer to Figure C.24). While some of these improvements are still underway, they will eventually increase southern commercial traffic and also give continuity to freight flows between northern and southern Mexico by connecting their transportation infrastructure (south with central and northern Mexico).

Figure C.24: Extension of Corridors for Plan Puebla Panama

(Source: Ministry of Communications and Transports, 2003)

One of the steps taken by the Ministry of Communications and Transports in Mexico to improve southern transportation infrastructure is the increase in the budget devoted to highway infrastructure for that region. Figure C.25 shows the budget for highway infrastructure construction and maintenance in Mexico for years 2001, 2002 and 2003. Notice that for 2003 more than 60 percent of the budget was invested in southern infrastructure.

Figure C.25: Highway Infrastructure Budget in Mexico for 2003 (numbers in Millions of Pesos, 1 Peso = 0.0862 US DLLS)

(Source: Plan Puebla Panamá, 2004)

Plan Puebla Panama has other projects that will help to increase the number of commercial corridors and commercial traffic in the southern zone. Some of these projects are:

1. The Pacific Corridor: the objective of this project is the construction and maintenance of the corridor connecting Panama City and Puebla in Mexico through the pacific coast.
2. The Atlantic Corridor: the objective of this corridor is the construction, rehabilitation and maintenance of the corridor that connects Mexico, Belize, Guatemala, Honduras and El Salvador. This corridor will also help to connect the future maritime port of Cutuco (this port will start operations in 2005) (Port of Cutuco, 2004) located in El Salvador in the Pacific Coast with Honduras in the Atlantic coast and the port of Coatzacoalcos in Mexico.
3. Complementary Regional Connections: this project will help to integrate the main production and distribution centers with the international ports from the Panama Canal to the Mexican border with the United States and Texas (Plan Puebla Panama, 2004).

The main corridors for domestic air cargo are: Guadalajara – Mexico City – Guadalajara, Tijuana – Mexico City – Tijuana, Monterrey – Mexico City – Tijuana. In southern Mexico the main corridors are Merida – Mexico City – Merida, and Cancún – Mexico City – Cancún. Notice that Mexico City is either

the place of origin or destination for seventeen of twenty corridors (refer to Table C.12). Mexico City is the main destination for domestic freight, but it is not the main origin. This results in empty returning flights and an imbalance of freight flows affecting the operations, tariffs and efficiency of air cargo services.

Table C.12
Main Air Cargo Corridors in Mexico

Corridor		Flights	Freight (kg)
GUADALAJARA	MÉXICO	27,333	8,274,144
TIJUANA	MÉXICO	20,389	7,888,442
MONTERREY	MÉXICO	24,799	7,832,997
MÉRIDA	MÉXICO	9,198	6,455,809
CANCÚN	MÉXICO	16,066	5,261,320
SAN LUIS	MÉXICO	5,697	2,981,050
POTOSÍ	MÉXICO		
VILLAHERMOSA	MÉXICO	7,793	2,702,806
MEXICALI	MÉXICO	3,562	2,239,359
HERMOSILLO	TIJUANA	5,121	2,140,452
HERMOSILLO	MÉXICO	9,587	2,058,043
TIJUANA	GUADALAJARA	13,326	1,997,411
TUXTLA	MÉXICO	6,229	1,841,018
GUTIÉRREZ			
PUERTO	MÉXICO	4,913	1,780,046
VALLARTA			
VERACRUZ	MÉXICO	6,087	1,570,442
MONTERREY	SAN LUIS		
	POTOSÍ	2,979	1,556,958
CD. JUÁREZ	MÉXICO	5,217	1,549,209
OAXACA	MÉXICO	5,977	1,540,981
ACAPULCO	MÉXICO	7,533	1,470,000
CHIHUAHUA	MÉXICO	5,068	1,425,272
SAN JOSÉ DEL			
CABO	MÉXICO	2,770	1,421,673

Source: Martner et al., 2003.

As discussed previously, intermodal transportation is used in Mexico only for imports. Therefore, the most important intermodal corridors in Mexico have an origin either in a border with the United States or in a maritime port. The most important intermodal corridors in Mexico are:

- Tijuana – Mexico City (through Guadalajara and Querétaro)
- Cd. Juárez – Guadalajara (through Chihuahua and Torreón)
- Cd. Juárez – Mexico City (through Chihuahua and Torreón)
- Nuevo Laredo – Mexico City – Toluca (through Monterrey and San Luis Potosí)
- Manzanillo – Guadalajara – Mexico City.
- Veracruz – Mexico City - Guadalajara
- Veracruz – Manzanillo
- Veracruz - Merida
- Lázaro Cárdenas – Mexico City – Nuevo Laredo
- Altamira – Mexico City (through San Luis Potosí and Querétaro)
- Progreso – Coatzacoalcos – Mexico City (Mexican Railroad Companies, 2004).

APPENDIX D

STAN Solution Algorithm

The most common solution method for traffic assignment problems is the linear optimization method of Frank and Wolfe. "This method, which is commonly used for solving large scale network equilibrium problems, has a sublinear rate of convergence in the vicinity of the optimal solution". (Guélat et al., 1990).

Guelat et al. explained the following: The structure of the model adapted from Frank and Wolfe and used in STAN, suggests a natural decomposition by product. A problem considered is given in a compact form as

$$\text{Min } F(u), \text{ subject to } u \in \Omega$$

It is assumed that $F(u)$ is a convex function, once differentiable on an open space that contains Ω . Ω is the direct product $\prod_p \Omega^p$, where Ω^p is the set of feasible flows of product p on the subnetworks $m(p) \in M(p)$. The descent direction of the linear approximation method is found by minimizing the linear approximation of the objective function, which in this case would be F^p ($F = \sum_{p=1}^{n_p} F^p$); thus one would have to solve n_p subproblems in a cycle of the algorithm. For each product p , a descent direction is computed for u^p which is of dimension $(n_A + n_T)$. When considering a particular product, all the flow variables pertaining to the other products are kept at their previous value.

For each product p , a single iteration of the linear approximation algorithm is carried out. The statement of the algorithm is as follows:

Step 0. Initialization

Determine u (initial feasible solution)

Step 1. Major cycle

$u_{old} = u$; for each $p \in P$ carry out (1p).

(1p) Minor cycle

Compute $c^p(u)$ (marginal costs)

Find ω^p (extreme point found by shortest path computations)

$d^p = \omega^p - u^p$ (descent direction)

Compute λ^p (optimal step size)

$u^p = u^p + \lambda^p d^p$ (update flow for p)

Step 2. Stopping criterion

If ($u \neq u_{old}$), return to Step 1.

The algorithm is stopped when the flows u do not change after a major cycle was carried out and the current solution is optimal. In practice, the function F may be used to construct a stopping criterion based on the relative gap (RG) defined as:

$$RG = 100 * (F(u) - BLB(u)) / F(u)$$

Where $BLB(u)$ represents the best lower bound obtained during the previous major cycles carried out. This lower bound is computed by solving the linear programming problem

$$\min VF(u)y, \text{ subject to } y \in \Omega$$

A lower bound on the optimal solution $F(u) + VF(u)(y^* - u)$, where y^* is the optimal solution of the above problem.

APPENDIX E

TRUCK TRAILERS			
TYPE	NUMBER OF AXLES	NUMBER OF TIRES	VEHICLE CONFIGURATION
T2-S1	3	10
T2-S2	4	14
T3-S2	5	18
T3-S3	6	22

Truck Trailer (T3-S2)

General characteristics

- Number of axles: Truck of three axles
- Brand: INTERNATIONAL 9200i
- Type of engine: DETROIT DIESEL MOTOR S-60 430 HP
- Trailer: 40 feet trailer with two axles
- Type of tires: 1100-20.00 normal
- Empty weight: 17 436 kg
- Maximum load: 25 000 kg
- Power (hp): 430 hp

MAXIMUM TRUCK GROSS WEIGHT					
TYPE OF TRUCK	NUMBER OF TIRES	TYPE OF HIGHWAY			
		A4 Y A2	B4 Y B2	C	D
T2-S1	10	27.50	27.50	24.50	NA
T2-S2	14	35.50	35.50	31.50	NA
T3-S2	<u>18</u>	<u>44.00</u>	<u>44.00</u>	<u>39.00</u>	<u>NA</u>
T3-S3	22	48.50	48.50	43.00	NA

APPENDIX F

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☐ DELETE
☐ MODIFY
☒ LIST

TRANSFER:
☒ ALL DATA
☐ FUNCTION SET
☐ PHI COEFF.
☐ USER DATA 1
☐ USER DATA 2
☐ USER DATA 3
☒ TWO-WAY TRANS

OPTIONS:
☐ STATUS
☐ NUMERIC INPUT
☐ USE SAME DATA
☐ NEXT TR. NODE
☐ UPDATE PLOT
☐ RESTART
☐ QUIT

STAN
DATE: 04-10-31
MODULE: 2.22
CARLETON...CVA
SCENARIO: 1000
LL:-2.667/ -2
UR:2.6667/ 2

```
graph TD; 1431((1431)) --- 3708((3708)); 1431((1431)) --- 1459((1459)); 3708((3708)) --- 1459((1459)); 1431((1431)) -.-> 4((4)); 1459((1459)) -.-> 4((4)); 1431((1431)) -.-> 3708((3708)); 1459((1459)) -.-> 3708((3708));
```

start

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TRANSFER NODE
4

OPERATION:
☐ ADD
☐ DELETE
☐ MODIFY
☒ LIST

TRANSFER:
☒ ALL DATA
☐ FUNCTION SET
☐ PHI COEFF.
☐ USER DATA 1
☐ USER DATA 2
☐ USER DATA 3
☒ TWO-WAY TRANS

OPTIONS:
☐ STATUS
☐ NUMERIC INPUT
☐ USE SAME DATA
☐ NEXT IN. NODE
☐ UPDATE PLOT
☐ RESTART
☐ QUIT

STAN
 DATE: 04-10-31
 MODULE: 2.22
 CARLETON...CVA
 SCENARIO: 1000
 LI: -2.667/ -2
 UR: 2.667/ 2

start

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TRANSFER NODE
3706

OPERATION:
☐ ADD
☐ DELETE
☐ MODIFY
☒ LIST

TRANSFER:
☒ ALL DATA
☐ FUNCTION SET
☐ PHI COEFF.
☐ USER DATA 1
☐ USER DATA 2
☐ USER DATA 3
☒ TWO-WAY TRANS

OPTIONS:
☐ STATUS
☐ NUMERIC INPUT
☐ USE SAME DATA
☐ NEXT TR. NODE
☐ UPDATE PLOT
☐ RESTART
☐ QUIT

STAN
DATE: 04-10-91
MODULE: 2.22
CARLETON...CVA
SCENARIO: 1000
LL: -2.867/ -2
UR: 2.8667/ 2

```
graph TD; 1401((1401)) -- solid --> 1438((1438)); 1401 -- solid --> 1443((1443)); 1438 -.-> 1443; 1443 -.-> 1401;
```

Start

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TRANSFER NODE

2

OPERATION: ☐ ADD ☐ DELETE ☐ MODIFY ☒ LIST	TRANSFER: ☒ ALL DATA ☐ FUNCTION SET ☐ PHI COEFF. ☐ USER DATA 1 ☐ USER DATA 2 ☐ USER DATA 3 ☒ TWO-WAY TRANS.	OPTIONS: ☐ STATUS ☐ NUMERIC INPUT ☐ USE SAME DATA ☐ NEXT TR. NODE ☐ UPDATE PLOT ☐ RESTART ☐ QUIT	STAN DATE: 04-10-91 MODULE: 2.22 CASELTON: ...CVA SCENARIO: 1000 LL: -2.667/ -2 UR: 2.6667/ 2
---	--	---	--

Start

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TRANSFER NODE
1461

OPERATION:
☐ ADD
☐ DELETE
☐ MODIFY
☒ LIST

TRANSFER:
☒ ALL DATA
☐ FUNCTION SET
☐ PHI CORRF.
☐ USER DATA 1
☐ USER DATA 2
☐ USER DATA 3
☐ TWO-WAY TRANS.

OPTIONS:
☐ STATUS
☐ NUMERIC INPUT
☐ USE SAME DATA
☐ NEXT TR. NODE
☐ UPDATE PLOT
☐ RESTART
☐ QUIT

STAN
 DATE: 04-10-91
 MODULE: 2.22
 CARLETON...CVA
 SCENARIO: 1000
 LL: -2.867/ -2
 UR: 2.6667/ 2

start

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LT

TRANSFER NODE
1462

OPERATION:
☐ ADD
☐ DELETE
☐ MODIFY
☒ LIST

TRANSFER:
☒ ALL DATA
☐ FUNCTION SET
☐ PHI COEFF.
☐ USER DATA 1
☐ USER DATA 2
☐ USER DATA 3
☒ TWO-WAY TRANS

OPTIONS:
☐ STATUS
☐ NUMERIC INPUT
☐ USE SAME DATA
☐ NEXT TR. NODE
☐ UPDATE PLOT
☐ RESTART
☐ QUIT

STAN
 DATE: 04-10-31
 MODULE: 2.22
 CASELTON: ...CVA
 SCENARIO: 1000
 LL: -2.667/ -2
 UR: 2.667/ 2

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LT

TRANSFER NODE
1403

OPERATION:
☐ ADD
☐ DELETE
☐ MODIFY
☒ LIST

TRANSFER:
☒ ALL DATA
☐ FUNCTION SET
☐ PHI CORRP.
☐ USER DATA 1
☐ USER DATA 2
☐ USER DATA 3
☒ TWO-WAY TRANS

OPTIONS:
☐ STATUS
☐ NUMERIC INPUT
☐ USE SAME DATA
☐ NEXT TR. NODE
☐ UPDATE PLOT
☐ RESTART
☐ QUIT

STAN:
 DATE: 04-10-91
 MODULE: 2.32
 CASELTON...CVA
 SCENARIO: 1000
 LL: -2.667/ -2
 UR: 2.6667/ 2

start

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LT

TRANSFER NODE
1394

OPERATION:
☐ ADD
☐ DELETE
☐ MODIFY
☒ LIST

TRANSFER:
☒ ALL DATA
☐ FUNCTION SET
☐ PHI COEFF.
☐ USER DATA 1
☐ USER DATA 2
☐ USER DATA 3
☒ TWO-WAY TRANS

OPTIONS:
☐ STATUS
☐ NUMERIC INPUT
☐ USE SAME DATA
☐ NEXT TR. NODE
☐ UPDATE PLOT
☐ RESTART
☐ QUIT

STAN
 DATE: 04-10-31
 MODULE: 2.22
 CARLETON...CVA
 SCENARIO: 1000
 LL: -2.667/ -2
 UR: 2.667/ 2

start

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TRANSFER NODE		STAN	
1401		DATE: 04-10-91	MODULE: 2.22
		CARLETON...CVA	SCENARIO: 1000
		LL:-2.667/	-2
		UR:2.6667/	2

OPERATION:	TRANSFER:	OPTIONS:
☐ ADD	☒ ALL DATA	☐ STATUS
☐ DELETE	☐ FUNCTION SET	☐ NUMERIC INPUT
☐ MODIFY	☐ PHI COEFF.	☐ USE SAME DATA
☐ LIST	☐ USER DATA 1	☐ NEXT TR. NODE
	☐ USER DATA 2	☐ UPDATE PLOT
	☐ USER DATA 3	☐ RESTART
	☐ TWO-WAY TRANS.	☐ QUIT

start

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LT

TRANSFER NODE
1186

OPERATION:
☐ ADD
☐ DELETE
☐ MODIFY
☒ LIST

TRANSFER:
☒ ALL DATA
☐ FUNCTION SET
☐ PHI COEFF.
☐ USER DATA 1
☐ USER DATA 2
☐ USER DATA 3
☒ TWO-WAY TRANS.

OPTIONS:
☐ STATUS
☐ NUMERIC INPUT
☐ USE SAME DATA
☐ NEXT TR. NODE
☐ UPDATE PLOT
☐ RESTART
☐ QUIT

STAN
DATE: 04-10-31
MODULE: 2.22
CARLETON...CFA
SCENARIO: 1000
LL: -2.667/ -2
UR: 2.667/ 2

start

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TRANSFER NODE
1180

OPERATION:	TRANSFER:	OPTIONS:	STAN
☐ ADD ☐ DELETE ☐ MODIFY ☒ LIST	☒ ALL DATA ☐ FUNCTION SET ☐ PHI CORRP. ☐ USER DATA 1 ☐ USER DATA 2 ☐ USER DATA 3 ☒ TWO-WAY TRANS	☐ STATUS ☐ NUMERIC INPUT ☐ USE SAME DATA ☐ NEXT TR. NODE ☐ UPDATE PLOT ☐ RESTART ☐ QUIT	DATE: 04-10-31 MODULE: 2.22 CARLETON...CVA SCENARIO: 1000 LL:-2.667/ -2 UR:2.6667/ 2

1156 1174 1186 1193 1

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LT

TRANSFER NODE
1156

OPERATION:
☐ ADD
☐ DELETE
☐ MODIFY
☒ LIST

TRANSFER:
☒ ALL DATA
☐ FUNCTION SET
☐ PHI COEFF.
☐ USER DATA 1
☐ USER DATA 2
☐ USER DATA 3
☒ TWO-WAY TRANS.

OPTIONS:
☐ STATUS
☐ NUMERIC INPUT
☐ USE SAME DATA
☐ NEXT TR. NODE
☐ UPDATE PLOT
☐ RESTART
☐ QUIT

STAN
 DATE: 04-10-31
 MODULE: 2.22
 CARLETON...CVA
 SCENARIO: 1000
 LL: -2.667/
 UR: 2.6667/ 2

Start

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LT

TRANSFER NODE
1193

OPERATION:
☐ ADD
☐ DELETE
☐ MODIFY
☒ LIST

TRANSFER:
☒ ALL DATA
☐ FUNCTION SET
☐ PHI COEFF.
☐ USER DATA 1
☐ USER DATA 2
☐ USER DATA 3
☒ TWO-WAY TRANS

OPTIONS:
☐ STATUS
☐ NUMERIC INPUT
☐ USE SAME DATA
☐ NEXT TR. NODE
☐ UPDATE PLOT
☐ RESTART
☐ QUIT

STAN
 DATE: 04-10-31
 MODULE: 2.22
 CARLETON...CVA
 SCENARIO: 1000
 LL: -2.667/ -2
 UR: 2.6667/ 2

start

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LT

TRANSFER NODE
1188

OPERATION:
☐ ADD
☐ DELETE
☐ MODIFY
☒ LIST

TRANSFER:
☒ ALL DATA
☐ FUNCTION SET
☐ PHI CORRECTION
☐ USER DATA 1
☐ USER DATA 2
☐ USER DATA 3
☒ TWO-WAY TRANS.

OPTIONS:
☐ STATUS
☐ NUMERIC INPUT
☐ USE SAME DATA
☐ NEXT TR. NODE
☐ UPDATE PLOT
☐ RESTART
☐ QUIT

STAN:
 DATE: 04-10-91
 MODULE: 2.22
 CARLETON...CVA
 SCENARIO: 1000
 LL: -2.667/-2
 UR: 2.667/2

start

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APPENDIX G

Summary comparison of volume vs. capacity

Products	Links	Average Capacity (veh/day)	Cargo Volume Assigned (ton/day)	Cargo Volume Assigned (%)	Number of vehicles on links
Cement	Toll Roads	188,349	44,173	2	1,921
	Free Roads	58,976	1,366,951	27	59,433
Combustoleo	Toll Roads	188,349	107,697	8	5,385
	Free Roads	64,057	2,153,265	54	107,663
Corn	Toll Roads	188,349	0	0	0
	Free Roads	64,057	0	0	0
Wood	Toll Roads	188,349	0	0	0
	Free Roads	64,057	0	0	0

Please note that these are aggregate results of the optimized system. Since there are over 200 links, only the summary results are shown.

APPENDIX H

Stan Reports

Each mode of transportation is represented by a different line in different colours as indicated in each report.

Note: The yellow line represents southeast Mexico boundaries.

STAN Module: 6.01 Date: 05-01-17 21:27 User: S050/CARLETON..CVA
 Project: Freight Transportation in Southeast Mexico
 Scenario 1000: Current situation optimization

MINCOST ASSIGNMENT

Scen. 1000 - Network size: 12 centroids
 80 regular nodes
 274 active links
 392 active transfers

Modes: a Toll Roads c Free roads n Connector
 r Railway

Mincost assignment: 04-11-03 23:38
 Product Demand Modes
 Cement mf01 acnr
 Combustoleo mf02 acnr
 Corn mf03 acnr
 Wood mf04 acnr
 **** Matrix deleted or modified ****

Generalized cost: 1*(operating cost) + 1*(delay cost) + 1*(other cost)
 Stopping criteria: maximum number of iteration(s)= 35 gap= 0.05%

Results:
 Current iteration: 35
 Objective function value: 0.228206E+08
 Best lower bound: 0.225812E+08
 Gap: 1.05 %

Cost component values: Operating cost value: 0.206391E+08
 Delay cost value: 0.185898E+07
 Other cost value: 0.322538E+06

Number of iterations: 35 stopped by: iter

-->

STAN Module: 6.01 Date: 05-01-17 21:37 User: S050/CARLETON..CVA
Project: Freight Transportation in Southeast Mexico
Scenario 1000: Current situation:optimization

RESULT SUMMARY BY MODE

Selected products: all
Selected modes: acnr
Selected links: all

LINKS		
Mode	Number	Length (km)
a	24	1574.00
c	174	10430.00
n	24	.00
r	52	3852.00
Total	274	15857.33

TRANSFERS

----- To Mode -----				
From Mode	a	c	n	r
a	0	47	7	8
c	47	0	30	86
n	7	30	0	18
r	8	86	18	0
Total	62	163	55	112
----->				
				Total
				62
				163
				55
				112
				392

STAN Module: 6.01 Date: 05-01-17 21:38 User: S050/CARLETON..CVA
 Project: Freight Transportation in Southeast Mexico
 Scenario 1000: Current situation:optimization

RESULT SUMMARY BY MODE

RESULT SUMMARY FOR PRODUCT 1 : Cement

DEMAND AND SUBNETWORK

Matrix	Total demand	Assigned	Modes	Active links	Active transfers
mf01	89239.0	89239.0	acnr	274	392

VOLUMES ON LINKS

Node	t			Unused links	t			Total
	Minimum	Average	Maximum		Minimum	Average	Maximum	
a	.00	430.73	6041.05	21	.0	196.4	238621.7	309211.2
c	.00	935.83	14378.60	152	.0	917.4	1649728.	9568658.
n	.00	7436.58	61737.00	16	.0	.0	.0	.0
x	.00	8290.26	59588.81	26	.0	8614.9	4539797.	33184444
Total		2856.72	782742.6	215		2715.8		43062312

--->

STAN Module: 6.01 Date: 05-01-17 21:39 User: S050/CARLETON..CVA
Project: Freight Transportation in Southeast Mexico
Scenario 1000: Current situation:optimization

RESULT SUMMARY BY MODE

COSTS ON LINKS

Mode	Unit costs				Total (\$)
	Minimum (\$ /t)	Average (\$ /t)	Maximum (\$ /t)		
a	.00	38.72	124.40		185482.9
c	.00	29.81	133.30		4702737.5
n	.00	.00	.00		.0
r	1.50	10.01	42.32		4990970.5
Total		24.22			9879191.0

VEHICLES ON LINKS

Mode	Vehicles			Vehicle-km		
	Minimum	Average	Maximum	Minimum	Average	Maximum
a	0	19	263	0.	9.	10375.
c	0	41	625	0.	40.	71727.
n	0	7437	61737	0.	0.	0.
r	0	115	828	0.	120.	63053.
Total		701	191995		56.	890368.

-->

STAN Module: 6.01 Date: 05-01-17 21:41 User: S050/CARLETON..CVA
Project: Freight Transportation in Southeast Mexico
Scenario 1000: Current situation:optimization

RESULT SUMMARY BY MODE

RESULT SUMMARY FOR PRODUCT 2 : Combustoleo

DEMAND AND SUBNETWORK

Matrix	Total demand	Assigned	Modes	Active links	Active transfers
mf02	29138.0	29138.0	acnr	274	392

VOLUMES ON LINKS

Mode	t			t			-km	
	Minimum	Average	Maximum	Unused links	Minimum	Average	Maximum	Total
a	.00	1448.88	17386.52	22	.0	479.0	686767.7	753879.7
c	.00	1400.84	20314.00	155	.0	1445.1	1767318.	15072860
n	.00	2428.17	28016.00	19	.0	.0	.0	.0
x	.00	3238.34	22808.00	40	.0	3534.9	2163640.	13616334
Total		1843.76	505189.1	236		1856.9		29443072

-->

STAN Module: 6.01 Date: 05-01-17 21:41 User: S050/CARLETON..CVA
 Project: Freight Transportation in Southeast Mexico
 Scenario 1000: Current situation:Optimization

RESULT SUMMARY BY MODE

COSTS ON LINKS

Mode	Unit costs			Total (\$)
	Minimum (\$ /t)	Average (\$ /t)	Maximum (\$ /t)	
a	.00	44.52	143.06	594232.4
c	.00	34.28	153.30	8103498.0
n	.00	.00	.00	.0
x	1.57	10.05	37.85	2130229.5
Total		27.59		10827960.0

VEHICLES ON LINKS

Mode	Vehicles			Vehicle-km		
	Minimum	Average	Maximum	Minimum	Average	Maximum
a	0	72	869	0.	24.	34338.
c	0	70	1016	0.	72.	88366.
n	0	2428	28016	0.	0.	0.
x	0	47	331	0.	51.	31357.
Total		272	74642		62.	988675.

-->

STAN Module: 6.01 Date: 05-01-17 21:42 User: S050/CARLETON..CVA
 Project: Freight Transportation in Southeast Mexico
 Scenario 1000: Current situation:optimization

RESULT SUMMARY BY MODE

RESULT SUMMARY FOR PRODUCT 3 : Corn

DEMAND AND SUBNETWORK

Matrix	Total demand	Assigned	Modes	Active links	Active transfers
mf03	18500.0	18500.0	acnr	274	392

VOLUMES ON LINKS

Node	t			Unused links	t			Total
	Minimum	Average	Maximum		Minimum	Average	Maximum	
a	.00	.00	.00	24	.0	.0	.0	.0
c	.00	.00	.00	174	.0	.0	.0	.0
n	.00	1541.67	15974.00	20	.0	.0	.0	.0
f	.00	1755.19	11137.00	35	.0	1724.3	802942.0	6641852.0
Total		468.14	128270.0	253		418.9		6641852.0

STAN Module: 6.01 Date: 05-01-17 21:43 User: S050/CARLETON..CVA
 Project: Freight Transportation in Southeast Mexico
 Scenario 1000: Current situation:optimization

RESULT SUMMARY BY MODE

COSTS ON LINKS

Mode	Unit costs			Total (\$)
	Minimum (\$ /t)	Average (\$ /t)	Maximum (\$ /t)	
a	.00	74.21	238.43	.0
c	.00	57.14	255.50	.0
n	.00	.00	.00	.0
x	1.44	8.42	34.49	754028.7
Total		44.38		754028.7

VEHICLES ON LINKS

Mode	Vehicles			Vehicle-km		
	Minimum	Average	Maximum	Minimum	Average	Maximum
a	0	0	0	0.	0.	0.
c	0	0	0	0.	0.	0.
n	0	1542	15974	0.	0.	0.
x	0	23	148	0.	23.	10706.
Total		139	38217		6.	

-->

STAN Module: 6.01 Date: 05-01-17 21:43 User: S050/CARLETON..CVA
 Project: Freight Transportation in Southeast Mexico
 Scenario 1000: Current situation: optimization

RESULT SUMMARY BY MODE

RESULT SUMMARY FOR PRODUCT 4 : Wood

DEMAND AND SUBNETWORK

Matrix	Total demand	Assigned	Nodes	Active links	Active transfers
mf04	4733.0	4733.0	acnr	274	392

VOLUMES ON LINKS

Node	t			t			-km		
	Minimum	Average	Maximum	Unused links	Minimum	Average	Maximum	Total	
a	.00	.00	.00	24	.0	.0	.0	.0	
c	.00	.00	.00	174	.0	.0	.0	.0	
n	.00	394.42	4733.00	22	.0	.0	.0	.0	
r	.00	273.06	4733.00	49	.0	186.1	523943.1	717049.5	
Total		86.37	23665.00	269		45.2		717049.5	

-->

STAN Module: 6.01 Date: 05-01-17 21:44 User: S050/CARLETON..CVA
Project: Freight Transportation in Southeast Mexico
Scenario 1000: Current situation:optimization

RESULT SUMMARY BY MODE

COSTS ON LINKS

Mode	Unit costs			Total (\$)
	Minimum (\$ /t)	Average (\$ /t)	Maximum (\$ /t)	
a	.00	68.50	220.09	.0
c	.00	52.74	235.85	.0
n	.00	.00	.00	.0
r	1.66	9.63	39.80	75986.0
Total		41.32		75986.0

VEHICLES ON LINKS

Mode	Vehicles			Vehicle-km		
	Minimum	Average	Maximum	Minimum	Average	Maximum
a	0	0	0	0	0	0
c	0	0	0	0	0	0
n	0	394	4733	0	0	0
r	0	4	73	0	3	8061
Total		35	9684		1	11032

-->

STAN Module: 6.01 Date: 05-01-17 21:44 User: S050/CARLETON..CVA
 Project: Freight Transportation in Southeast Mexico
 Scenario 1000: Current situation:optimization

RESULT SUMMARY BY MODE

AGGREGATED RESULT SUMMARY (all products)

VOLUMES ON LINKS

Mode	Minimum	Average	Maximum	Total	Unused links	Minimum	Average	Maximum	Total
a	.00	1879.60	23427.58	45110.48	21	.0	675.4	925389.3	1063091.
c	.00	2336.67	34104.00	406580.3	150	.0	2362.6	2967048.	24641518
n	.00	11800.83	61737.00	283220.0	9	.0	.0	.0	.0
r	.00	13556.85	59588.81	704956.1	19	.0	14060.1	5914689.	54159684
Total		5254.99		1439867.	199		5036.8		79864288

TOTAL COSTS ON LINKS

Mode	Total cst (\$)
a	779715.3
c	12806236.
n	.0
r	7951215.0
Total	21537166.

-->

STAN Module: 6.01 Date: 05-01-17 21:45 User: S050/CARLETON..CVA
Project: Freight Transportation in Southeast Mexico
Scenario 1000: Current situation:optimization

RESULT SUMMARY BY MODE

VOLUMES ON TRANSFERS (t)

From Mode	To Mode				Total
	a	c	n	x	
a	.00	45110.48	.00	.00	45110.48
c	42962.29	.00	54820.22	25968.65	123751.17
n	2148.19	19043.47	.00	120418.35	141610.00
x	.00	59597.21	86789.78	.00	146387.00
Total	45110.48	123751.17	141610.00	146387.00	456858.65

TOTAL COSTS ON TRANSFERS (\$)

From Mode	To Mode				Total
	a	c	n	x	
a	.0	.0	.0	.0	.0
c	.0	.0	.0	389529.8	389529.8
n	.0	.0	.0	.0	.0
x	.0	893958.2	.0	.0	893958.2
Total	.0	893958.2	.0	389529.8	1283488.0

-->