Managing Freight Transportation and Air Quality in the Mexico City Metropolitan Area

by

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B.S. Civil Engineering
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Abstract

In the planning and management of freight transportation systems, there may be difficult challenges to providing efficient movements of goods in a region and achieving environmental objectives. Managing these potential conflicts is important to ensure the economic benefits of an efficient freight transportation system while minimizing its negative effects, such as air pollution.

In this thesis we analyze the freight transportation system of the Mexico City Metropolitan Area (MCMA), one of the largest and most polluted cities in the world. Freight transportation has played a very import role in the economic growth of the MCMA by providing the movement of goods into and out of the region; however, it has also contributed substantially to its air quality deterioration.

Our main focus on this thesis has been with respect to exploring freight-related strategies to substantially improve air quality in the MCMA. These strategies are based on the use of newer and cleaner technologies for freight vehicles, as well as better managing and operating the freight fleet in the MCMA. In order to test these strategies a model linking freight demand, pollutant emissions and costs was developed. The results of our analysis show that it could be possible to achieve substantial and sustained freight emissions reductions by using newer and cleaner technologies for freight vehicles, as well as better operating the freight fleet in the MCMA. The costs associated with these strategies are also discussed.

Throughout the analysis multiple sources of uncertainty are identified and addressed. The analysis and results presented in this thesis could be used by decision-makers to improve the freight transportation system in the MCMA. Based on our analysis decision-makers can judge what type of pollutant emissions they wish to reduce and better understand what freight-related strategies should be implemented in the MCMA, as well as their performance with respect to the main sources of uncertainty identified. Therefore, if implemented, they could help achieve a viable freight transportation system in the MCMA to support its economic growth.

Thesis Advisor: Joseph M. Sussman
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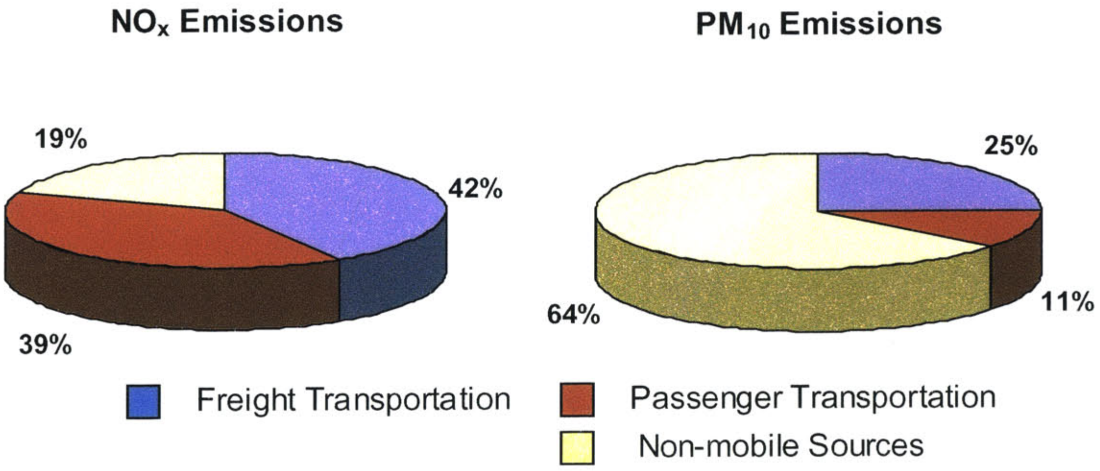
CHAPTER 1: INTRODUCTION

1.1 Motivation

In the planning and management of freight transportation systems, decision-makers are often faced with environmental and economic challenges to providing efficient movements of goods in a region. Freight transportation often plays a very important role in the economic growth of a region by providing the movement of goods into and out of a region, as well as within it. However, associated with this key contribution to economic growth there is a substantial negative impact of freight transportation in the environment. For instance, in the Mexico City Metropolitan Area (MCMA) it has been estimated that 41% of all NO_x and PM_{10}[1] emissions are directly attributable to freight vehicles[2], as shown in figure 1-1.

Figure 1-1 Freight Transportation Contribution to Pollutant Emissions in the Mexico City Metropolitan Area



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[1] NO_x = nitrogen oxides; PM_{10} = particulate matter

[2] PROAIRE (2002)

This conflict between economic growth enabled by transportation and its impact on the environment is evident in the case of the Mexico City Metropolitan Area. The MCMA is the largest city in Mexico and the biggest contributor to the country's economy[3]. However, in the past few decades air quality in the MCMA has deteriorated to the point of being considered one of the most polluted cities in the world, which in turn has caused a sever decline in the quality of life of its residents. While it is desirable to maintain the high economic growth in the MCMA, it is also desirable to improve its air quality. In fact, reduction in air quality of life is itself a drag on the economy. Therefore, the main motivation for this research is to decrease the negative environmental impact of freight transportation in the Mexico City Metropolitan Area while maintaining its key contribution to the economic growth of the region through the use of newer and cleaner technologies, as well as through better management of the freight transportation system.

1.2 Background of the Mexico City Metropolitan Area

The Mexico City Metropolitan Area (MCMA) is an example of what are commonly called "megacities". With nearly 18 million inhabitants[4], the MCMA is the largest city in the North American continent and among the largest in the world. The MCMA is comprised of the Distrito Federal – DF (Federal District) and municipalities from the neighboring state Estado de Mexico- EM (State of Mexico). It includes sixteen "delegaciones" of the DF and at least twenty seven surrounding municipalities in the EM, covering an area of approximately 4,600 square kilometers.

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[3] The MCMA contributes to 30% of Mexico's the gross domestic product (GDP).

[4] INEGI (2002)

Figure 1-2 Mexico City Metropolitan Area

1.2.1 Socioeconomic Characteristics

Mexico City is the federal capital of Mexico, as well as the financial and industrial center of the country. Mexico's total gross domestic product (GDP) in year 2000 was USD$ 574.5, making it the thirteenth largest economy in the world. The MCMA contributed to approximately 30% of Mexico's GDP and over 50% of its industrial output[5], making a highly intensive economic region.

The MCMA's population is divided between the DF and the EM. Nearly 8.5 million people live in the DF and 12.6 million people in the EM. The GDP per capita in the DF in year 2000 was USD$13,089, nearly three times higher than that in the EM

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[5] World Bank Development Indicators (1998)

(USD$4,542)[6]. In comparison to Mexico's GDP per capita (USD$5,580), the DF's GDP per capita was 135% higher, while the EM's was 19% lower, which illustrates the marked income inequality between the inhabitants of the DF and the EM.

Within the MCMA, out of approximately 45,000 industrial establishments, 63% of them are located in the DF and 37% in the EM. Furthermore, of the nearly 270,000 commercial establishments, 62% are located in the DF and 38% in the EM[7].

The MCMA is also characterized by a complex political structure. Being the capital city of Mexico, the Federal Government is located within Mexico City. Within the MCMA the DF and EM are considered separate states; thus, they have their own governments. Furthermore, the "delegaciones" in the DF and the municipalities in the EM also have their own government structures. This overlapping of federal and local political jurisdictions makes any decision making process difficult and complex.

1.2.2Transportation Infrastructure in Mexico City

Mexico City, being the industrial and financial center of the country, is also a major hub of Mexico's transportation system. Major highways and railroads connect the MCMA to the rest of the country. An international airport is located inside the DF. Within the MCMA there are nine railroad terminals, four of them located in the DF and the other five in the EM, as shown in table 1-1.

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[6] INEGI (2000)

[7] SETRAVI (1996)

Table 1-1 Railroad Terminals in the MCMA

Railroad Terminal	Location
Pantaco	DF
Santa Julia	DF
Tacuba	DF
San Pedro de los Pinos	DF
Tlalnepantla	EM
Xalostoc	EM
Lechería	EM
Ecatepec	EM
Los Reyes	EM

Source: SETRAVI (1996)

Within the MCMA, road transportation is characterized by highly congested streets, many of which are not suitable for freight vehicles[8]. The congestion can be partly explained by the fact that the high growth in population and motorization in the past few decades has outpaced infrastructure investments. Within the MCMCA, the majority of the roadway infrastructure is located in the DF, as shown in table 1-2.

Table 1-2 Major Roadway Infrastructure in the MCMA

Type of Roadway	DF	EM	Units
Highways	200	352	km
Urban Arterials	310	47	km
Primary Roads	553	617	km
Secondary Roads	8000	n/a	km

Source: COMETRAVI (1999)
Note: N/A = not available

Figure 1-3 shows the layout of the major roadways and rail lines connecting the MCMA to other regions in the country.

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[8] SETRAVI (1996)

Figure 1-3 Roadway and Railroad Infrastructure in the Valley of Mexico

1.3 Objectives

The ultimate goal of this thesis is to understand and work towards achieving a balance between freight transportation's contribution to economic growth and its negative environmental impacts through the use of newer and cleaner technologies for freight vehicles, as well as better management and operations of the freight fleet. This involves understanding and modeling the dynamics behind the demand for freight transportation in the MCMA, as well as modeling any potential improvement strategies to be implemented. The costs associated with these strategies should also be considered.

The central questions we want to address in this thesis are the following:

1. How can freight transportation negative contribution to air quality in the MCMA be substantially reduced without hindering economic growth?

2. What are the best freight strategies to implement in the MCMA to improve air quality?

3. Can newer and cleaner technologies for freight vehicles be used to substantially improve air quality in the MCMA?

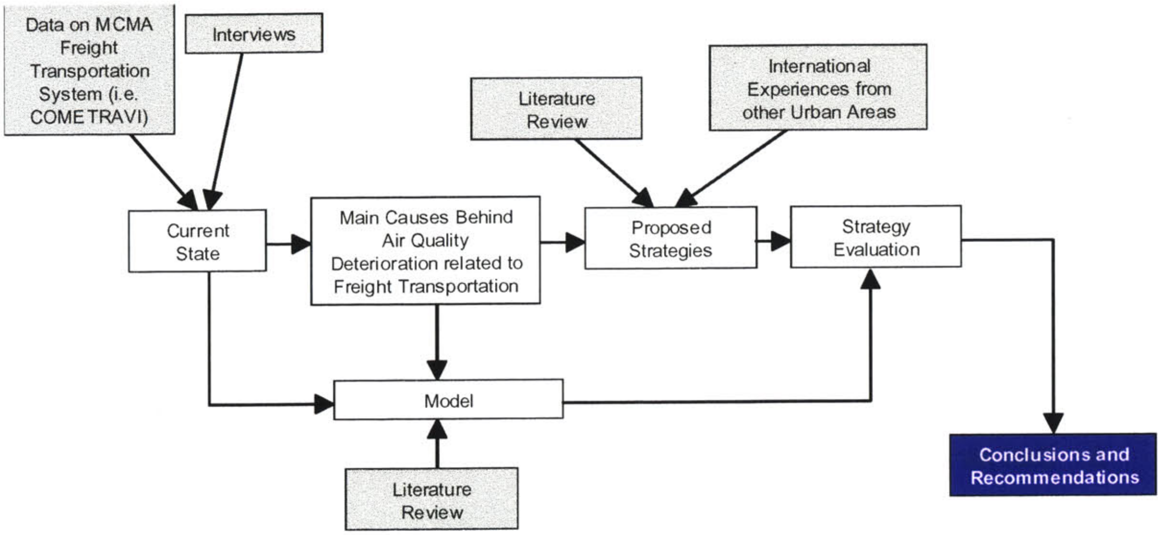
4. Can better management and operations of the freight fleet substantially improve air quality in the MCMA?

5. Can air quality improvements be substantial and sustained over a long period of time?

1.4 Methodology

This thesis aims to achieve its objectives and address the research questions presented by applying the methodology presented in figure 1-4.

Figure 1-4 Research Methodology



The detailed steps involved are the following:

1. Analyze and determine the current state of the freight transportation system in the Mexico City Metropolitan Area (MCMA) by reviewing published data (i.e. official data) and conducting interviews in the MCMA.

2. Identify the main causes behind air quality deterioration related to freight transportation in the MCMA.

3. Review the literature with respect to modeling of freight transportation demand in an urban area, as well as freight transportation pollutant emissions' modeling.

4. Review the literature with respect to identifying and modeling costs related to freight transportation.

5. Identify the main sources of uncertainties included in the planning process we are conducting and determine ways to handle them properly.

6. Develop a model that links freight transportation demand, pollutant emissions and costs of the MCMA's freight transportation. The model utilizes the best information available on freight transportation in the MCMA, as well as justified assumptions on socioeconomic, freight vehicle and cost parameters.

7. Review the literature with respect to freight transportation strategies aimed towards reducing pollutant emissions in urban areas. Similarly, review the literature with respect to freight transportation strategies aimed towards improving freight fleet operations in urban areas.

8. Explore and construct freight strategies that could potentially achieve pollutant emissions reductions in the MCMA. This includes strategies based on vehicle technology and fuel quality improvements, as well as strategies based on fleet operational and utilization improvements to achieve pollutant emissions reductions.

9. Evaluate these strategies using different criterions, such as their capability of achieving substantial emissions reductions.

10. Revise and combine strategies to create strategy packages (combined strategies) to be implemented in the MCMA.

11. Present the performance of each freight strategy with respect to different criterions, such as their capability of achieving substantial and sustained emissions reductions in the presence of uncertainty.

12. Draw conclusions and recommendations for the MCMA based on key findings.

1.5 Thesis Organization

The topics and questions to be addressed in this thesis are organized as follows:

Chapter Two

1) What are the components and main characteristics of the freight transportation system?
2) What are the key factors influencing pollutant emissions for freight vehicles?
3) What is freight transportation contribution to pollutant emissions in the MCMA?
4) Which are the key stakeholders included in the freight transportation system in the MCMA?

Chapter Three

1) How can we deal with the uncertainties inherent in the long planning horizons generally associated with transportation planning?
2) How can we model technological innovation and the rate of technology adoption in the MCMA?
3) What are the main drivers of freight transportation demand?
4) Presentation of the development of a deterministic vehicle based model that links freight transportation demand, pollutant emissions and economic and financial costs of the freight fleet. This model can be used to evaluate the benefits (pollutant emissions reductions) and financial and economic costs of various freight-related strategies to improve air quality in an urban area.
5) Discussion and justification of the assumptions used to develop the model.
6) How could freight transportation demand in the MCMA evolve in the future?
7) What will be the level of emissions, as well as the costs associated with the future behavior of freight transportation demand?

Chapter Four

1) Description of the freight strategies proposed by the government to improve air quality in the MCMA.
2) Would these strategies be capable of achieving substantial and sustained emissions reductions for key pollutants if implemented?
3) What would be the costs associated with these strategies if they are implemented and how would they be distributed?

Chapter Five

1) Description of freight strategies to reduce pollutant emissions using freight vehicle technology and fuel quality improvements.
2) What are the main mechanisms available to reduce freight vehicles' emissions using vehicle technology and fuel quality improvements?
3) Would these strategies be capable of achieving substantial and sustained emissions reductions for key pollutants?
4) What would be the costs associated with these strategies?
5) Which are the most cost-effective strategies?
6) What is their performance under the presence of uncertainty?
7) How can we use these strategies to construct combined strategies that are capable of achieving substantial and sustained emissions reductions?
8) What is the cost-effectiveness of these combined strategies?
9) What is their performance under the presence of uncertainty?

Chapter Six

1) Description of freight strategies to reduce pollutant emissions based on operational and utilization improvements of the freight fleet in the MCMA.
2) What is the potential of these strategies to achieve substantial and sustained emissions reductions?
3) Where have these strategies been implemented before and what can we learn from them?
4) What is the performance of these strategies under the presence of uncertainty?

5) Discussion of the use of both vehicle technology and fuel quality improvement strategies, as well as fleet operational and utilization improvement strategies to construct combined strategies.
6) Can these combined strategies achieve substantial and sustained emissions reductions? If so, what is their cost-effectiveness?
7) What is the performance of these strategies under the presence of uncertainty?

Chapter Seven

1) Review of Key Findings
2) Review of the Key Uncertainties and our handling of them.
3) Discussion of future enhancements to our analysis of freight transportation in the MCMA
4) Areas of Future Research

CHAPTER 2: MEXICO CITY METROPOLITAN AREA'S FREIGHT TRANSPORTATION SYSTEM

2.1 Introduction

This chapter presents an analysis of the freight transportation system in the MCMA. It describes the system's main components and their characteristics. In Chapter 1 we discussed freight transportation's contribution to the economic growth of a region which can be considered as positive. In this chapter we discuss its negative contribution to pollutant emissions in the MCMA. Finally, this chapter includes a description of the key stakeholders imbedded in the system, as well as their characteristics.

2.2 Current Freight Transportation System

A thorough analysis of a freight transportation system in any urban setting must start with a proper segmentation of its components. Such segmentation can be done using different criterions, such as type of vehicle used, i.e. trucks, railroad; the type of movements performed, i.e. local movements, intercity movements; the type of services offered, i.e. transportation services solely, integrated services (logistics and transportation); fleet ownership, i.e. privately owned fleets, among others. This segmentation, if done correctly, can help us explore and define the characteristics of each segmented identified, which in turn will improve our understanding the system's components, their behavior and dynamics. Thus, our ability to segment the system correctly and thoroughly will allow us to improve the quality of our analysis.

Following the segmentation presented in the document "Desarrollo de Políticas para el Mejoramiento del Ambiente relacionadas con el Transporte de Carga en la Zona Metropolitana del Valle de México (1996)" published by the Secretaria de Transporte y Vialidad[9] in 1996, the freight transportation system in the MCMA has been segmented

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[9] Secretary of Transportation (SETRAVI)

using three different criterions: 1) the type of vehicle used; 2) the type of movements performed and 3) fleet ownership.

From the type of vehicle used perspective, we can segment the system into two categories:

1. Road based vehicles: light duty gasoline trucks, light duty natural gas trucks, heavy duty diesel trucks, etc.
2. Railroad

Based on the type of movements performed, the freight transportation system can be segmented into three categories:

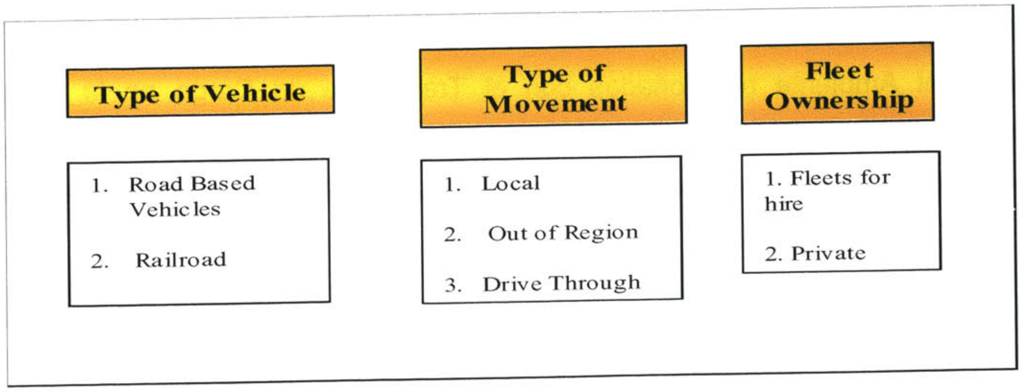
1. Local movements: movements with an origin and a destination within the MCMA.
2. Out of region movements: movements with either an origin or a destination outside the MCMA.
3. Drive through movements: movements with an origin and a destination both outside the MCMA.

Based on the fleet ownership, the system can be further segmented into two categories:

1. For hire freight fleets: companies whose business is the provision of freight transportation services to other companies.
2. Privately owned freight fleets: fleets belonging to private companies that use them to fulfill their own freight transportation needs.

Figure 2-1 summarizes the segmentation of the freight transportation system in the MCMA.

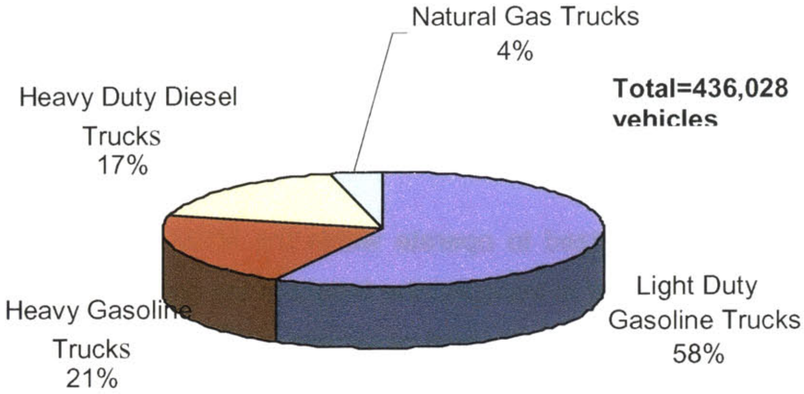
Figure 2-1 Freight Transportation System Segmentation



2.3 Road Based Freight Fleet Composition and Characteristics

The road based freight fleet in the MCMA[10] has been estimated to be comprised of approximately 436,000 vehicles, 58% of them being light duty gasoline trucks, 21% heavy gasoline trucks, 17% heavy duty diesel trucks and 4% light duty natural gas trucks.

Figure 2-2 Freight Transportation Vehicle Fleet



Source: Estimations based on figures included in "Programa para Mejorar la Calidad del Aire de la Zona Metropolitana del Valle de México 2002-2010 (PROAIRE)" and SETRAVI (1996).

Based on the segmentation presented earlier, six different road based freight segments have been identified: 1) local for hire fleet; 2) local private fleet; 3) out of region for hire fleet; 4) out of region private fleet; 5) drive through for hire fleet; 6) drive through private fleet. We will describe each segment's characteristics based on the data presented by SETRAVI (1996).

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[10] Including vehicles driving through the MCMA

2.3.1 Local For hire Fleet

The local for hire freight fleet is authorized to provide transportation services within the MCMA. This freight segment is composed mainly of single truck owners commonly called man-truck.

These truck owners have considerable financial, technological and infrastructure (i.e. operating facilities) limitations which limit their ability to offer competitive services.

The fleet has been estimated to include 22,456 vehicles; approximately 85% of them are light duty gasoline trucks and heavy gasoline trucks. The average age of the fleet has been estimated to be 16 years old, which makes them high pollutant emitters.

2.3.2 Local Private Fleet

The local private fleet is authorized to operate within the MCMA. The vehicles in this freight segment can only be used to transport the freight of the company that owns them; thus, they cannot be used to provide any kind of service to other companies. This freight segment contains the most number of vehicles in the MCMA. It has been estimated that 344,898 vehicles compose this segment, most of them being light duty gasoline trucks and heavy gasoline trucks (approximately 90%). The average age of the fleet has been estimated to be 10 years.

2.3.3 Out of Region and Drive through For Hire Fleet

The out of region for hire fleet and the drive through for hire fleet have similar characteristics. They are both authorized to provide interurban freight transportation services in the entire nation. The data available does not allow us to distinguish between the out of region fleet and the drive through fleet; however, it has been estimated that approximately 10% of the freight vehicles entering or leaving the MCMA do not have an origin or a destination within the MCMA, and thus belong to the drive through fleet. These two fleet segments are composed mostly by heavy duty diesel trucks with an average age of approximately 18 years.

2.3.4 Out of Region and Drive through Private Fleet

These two freight segments also have similar characteristics. The vehicles in both segments are authorized to transport freight of the company that owns them between cities in the entire nation. The data available does not allow us to distinguish between vehicles belonging to the out of region and drive through private fleet, but as with the out of region and drive through for hire fleets, it has been estimated that 10% of the freight vehicles entering or leaving the MCMA belong to the drive through fleet. Heavy duty diesel vehicles compose the majority of these freight segments and their average age has been estimated to be approximately 14 years old.

Collectively, the out of region for hire and private freight segments have been estimated to be composed of approximately 62,000 vehicles. Likewise, the drive through for hire and private freight segments have been estimated to be composed of 7,000 vehicles.

Table 2-1 summarizes the main characteristics of the road based freight fleet in the MCMA.

Table2-1 Road Based Freight Fleet Characteristics

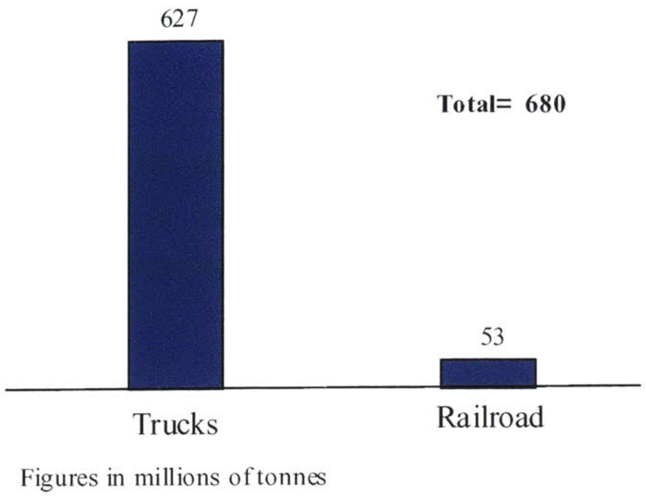
Fleet Component	Estimated Number of Vehicles	Average Age (years)	Percentage of Total Freight Fleet
Local for hire fleet	22,456	16	5%
Local private fleet	344,898	12	79%
Out of region for hire fleet	61,807	18	14%
Out of region private fleet		14	
Drive through for hire fleet	6,867	18	2%
Drive through private fleet		14	
Total	**436,028**		**100%**

Source: Estimations based on figures included in "Programa para Mejorar la Calidad del Aire de la Zona Metropolitana del Valle de México 2002-2010 (PROAIRE)" and SETRAVI (1996).

2.4 Railroad Participation in the MCMA

Railroad participation in the freight transportation system in Mexico as a nation and in the MCMA has historically been limited. In 1995, it was estimated that only 8% of all goods moved by trucks and railroad in Mexico used the latter as a means of transport, as shown in figure 2-3.

Figure 2-3 Freight Movements by Trucks and Railroad in Mexico in 1995



Source: Instituto Nacional de Estadística, Geografía e Informática

This low participation in the freight transportation system could change in the near and mid future. From its beginning in 1873 and up to 1997 the rail network in Mexico was owned by the government and operated by the for hire company Ferrocarriles Nacionales de Mexico (FNM). The services provided by FNM were not competitive with trucks (i.e. freight rates), their shipments were often late and the cargo damaged.

In 1997, the government privatized and divided the entire rail network in three regions which were sold to three different companies, Ferrocarriles Mexicanos (FERROMEX), Transportacion Ferroviaria Mexicana (TFM) and Ferrocarril del Sureste. These newly formed companies are joint ventures between Mexican investors and American railroad companies. For instance, FERROMEX is a joint venture between Grupo Mexicano S.A. de C.V. and Union Pacific Railroad; TFM is owned by Transportacion Maritima Mexicana (TMM) and Kansas City Southern Industries (KCS); and Ferrocarril del Sureste is owned by Grupo Ferroviario Mexicano and Union Pacific Railroad.

We do not have any data regarding service improvements associated with this privatization and its impact on freight transportation mode share, but it seems reasonable to assume that these companies offer a better service than FNM, which can help the railroad to gain a higher mode share in freight movements in Mexico and the MCMA.

2.5 Contribution to Key Pollutant Emissions

Based on their potential harm to human health, we will focus on four key pollutants throughout our analysis of freight transportation in the MCMA; non- methane hydrocarbons (NMHC), nitrogen oxides (NO_x) and suspended particulate matter (PM_{10}).

2.5.1 Brief Description of Key Pollutants

Non-methane Hydrocarbons (NMHC)

This pollutant is primarily produced from the incomplete combustion of fuels and other substances containing carbon. In the presence of sunlight, it may combine with nitrogen oxides and form smog or ozone. It is considered to be carcinogen and reduces respiratory system function.

Nitrogen Oxides (NO_x)

This pollutant is composed of NO and NO_2 derived from high temperature combustion in vehicle engines. It causes lung irritation, premature leaf loss and inhibition of plant growth, aggravates cardiovascular and respiratory diseases, and decreases visibility by contributing to ozone formation.

Suspended Particulate Matter (PM_{10})

Particulate matter is composed of suspended particles (diameters below 10 microns) in the atmosphere such as dust, metals, cement and organic compounds. The main sources of PM_{10} are carbon materials used in combustion of gasoline and diesel, industrial processes, road and forest erosion, and fires. PM10 can penetrate the respiratory system, causing damage to the pulmonary alveoli.

Other health impacts caused by these particles include irritation of the respiratory system, diseases like silicosis and asbestosis, and aggravation of other conditions such as asthma and cardiovascular diseases.

2.5.2 *Vehicle Emission Characteristics*

The type and amount of pollutant emitted by a vehicle depend on a number of factors, such as the type of fuel utilized, is traveling speed, the driving conditions in the network, the vehicle's age and size.

The type of fuel used by the vehicle: depending on the type of fuel used by a vehicle, its emissions' rates of key pollutants will be different. For example, diesel powered vehicles emit a higher amount of NOx and PM_{10}, but a lesser amount of NMHC than gasoline and natural gas powered vehicles, as shown in table 2-3.

Table 2-2 Key Pollutant Emission Rates for the Gasoline, Diesel and Gas Powered Vehicles

Freight Vehicle	**Emission rates (grams/mile)**		
	PM_{10}	**NO_x**	**NHMC**
Light Duty Gasoline Vehicle	0.08	0.63	0.44
Light Duty Diesel Vehicle	1.5	0.87	0.29
Light Duty Natural Gas Vehicle	0.03	0.75	0.45

Source: Environmental Protection Agency (EPA)

Vehicle and Engine Characteristics (weight and engine size): Emission rates also vary depending on the vehicle weight and its engine size measured as the number of cylinders. As a general rule, the heavier the vehicle, and the greater the number of cylinders in its engine, the greater the amount of pollutants it will emit per mile traveled. Table 2-3 illustrates the difference between light duty and heavy duty gasoline vehicles, as well as light duty and heavy duty diesel vehicles. From it we can notice that heavy duty vehicles (both gasoline and diesel) have considerably higher emission rates (grams/mile) than light duty vehicles.

Table 2-3. Key Pollutant Emission Rates for the Light and Heavy Duty Gasoline and Diesel Vehicles (grams/mile)

Freight Vehicle	Emission rates (grams/mile)		
	PM_{10}	NO_x	NHMC
Light-Duty Gasoline Vehicle	0.08	0.63	0.44
Heavy-Duty Gasoline Vehicle	1.2	2.83	1.39
Light-Duty Diesel Vehicle	1.5	0.87	0.29
Heavy-Duty Diesel Vehicle	2.41	8.13	4.83

Source: Environmental Protection Agency (EPA)

A better comparison between vehicle emissions could be made using emission rates as grams/tonne-mile instead of solely by grams/mile. Based on a vehicle's carrying capacity (tonnes) and average capacity utilization, we can determine how many tonnes a vehicle carries on average, which in turn can be used to determine the vehicle's pollutant emissions as grams/tonne-mile. Table 2-4 includes the carrying capacity and average capacity utilization of vehicles circulating in the MCMA.

Table 2-4 Average Carrying Capacity and Utilization for MCMA Freight Vehicles

Vehicle Type	Average Carrying Capacity (tonnes)	Average Capacity Utilization	Actual Carrying (tonnes)
Light-Duty Gasoline Vehicle	3	40%	1.2
Heavy-Duty Gasoline Vehicle	8	60%	4.8
Light-Duty Diesel Vehicle	3	40%	1.2
Heavy-Duty Diesel Vehicle	12	60%	7.2

Source: SETRAVI, 1996

Using the information from table 2-4 we can calculate emission rates for freight vehicles in the MCMA measured as grams/tonne-mile, as shown in table 2-5.

Table 2-5. Key Pollutant Emission Rates for the Light and Heavy Duty Gasoline and Diesel Vehicles (grams/tonne-mile)

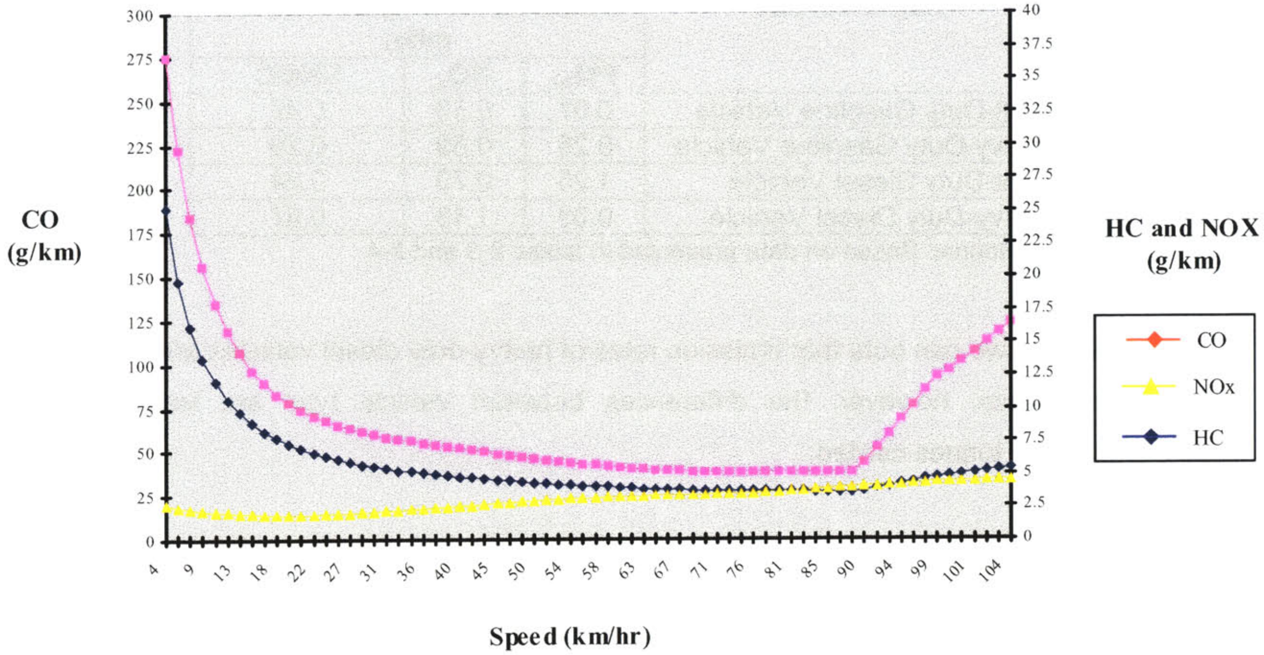
Freight Vehicle	**Emission rates (grams/tonne-mile)**		
	PM_{10}	**NO_x**	**NHMC**
Light-Duty Gasoline Vehicle	0.07	0.53	0.37
Heavy-Duty Gasoline Vehicle	0.25	0.59	0.29
Light-Duty Diesel Vehicle	1.25	0.73	0.24
Heavy-Duty Diesel Vehicle	0.33	1.13	0.67

Source: Based on data presented in tables 2-3 and 2-4

From this table we can note that emission rates of heavy-duty diesel vehicles are highest for all pollutants; however, the differences between vehicle type are less when considering the tonnes carried.

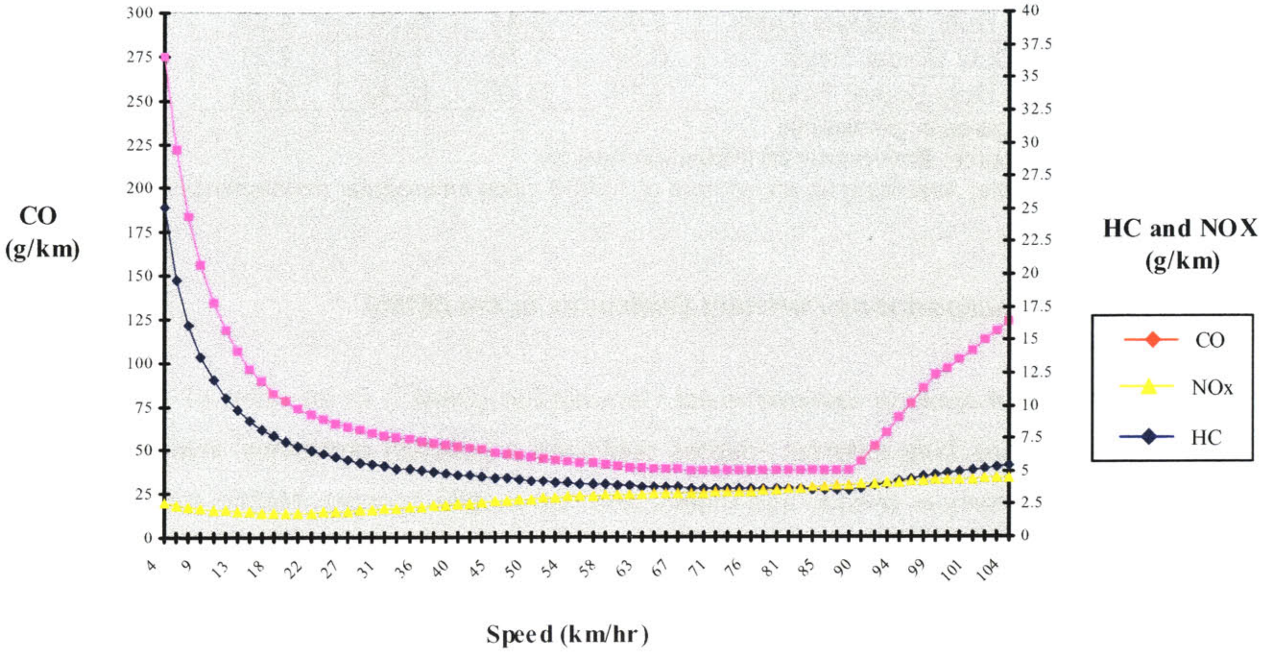
Vehicle driving cycle: A vehicle's driving cycle also influences emission rates. A vehicle will emit higher emission rates if it is constantly stopping and accelerating than if it is driving at a practically constant speed. Vehicles usually have a driving cycle with multiple stops and accelerations and considerably low speeds in a highly congested urban area, such as the MCMA. We do not have data regarding emissions and a vehicle's driving cycle; however, we can get an approximation looking at pollutant emission rates' behavior for different vehicle speeds. As shown in figures 2-4 and 2-5, low vehicle speeds (less than 30 km/hr) increase emissions' rates of HC, measured as g/km, substantially. Therefore, high levels of congestion are capable of increasing pollutant emissions' considerably in a region.

Figure 2-4 Emission Factors' Variation with Respect to Speed for a 1989 Heavy Duty Gasoline Truck



Source: "Programa para Mejorar la Calidad del Aire de la Zona Metropolitana del Valle de México 2002-2010 (PROAIRE)"

Figure 2-5 Emission Factors' Variation with Respect to Speed for a 1989 Heavy Duty Diesel Truck



Source: "Programa para Mejorar la Calidad del Aire de la Zona Metropolitana del Valle de México 2002-2010 (PROAIRE)"

Vehicle Age: A vehicle's age can also have a considerable impact on pollutant emission rates. As a vehicle's age increases, measured as total miles traveled, its emission rates will increase. Such an increase can be substantial, as it shown in table 2-6. From the table we can notice that NO_x emissions increase by a factor of five for a light duty gasoline truck from the time the vehicle is new to the time it is twenty years old. This increase can be even worse if the vehicle is not maintained properly.

Table 2-6 NO_x Emission Rates' Variation with Age for Different Freight Vehicles

Freight Vehicle	Vehicle Age (years)			
	0	10	15	20
Light Duty Gasoline truck	0.63	3.02	4.35	5.66
Heavy Duty Gasoline Truck	2.83	3.44	3.72	4.03
Light Duty Diesel Truck	0.87	1.78	1.99	2.21
Heavy Duty Diesel Truck	8.13	11.06	12.42	13.84

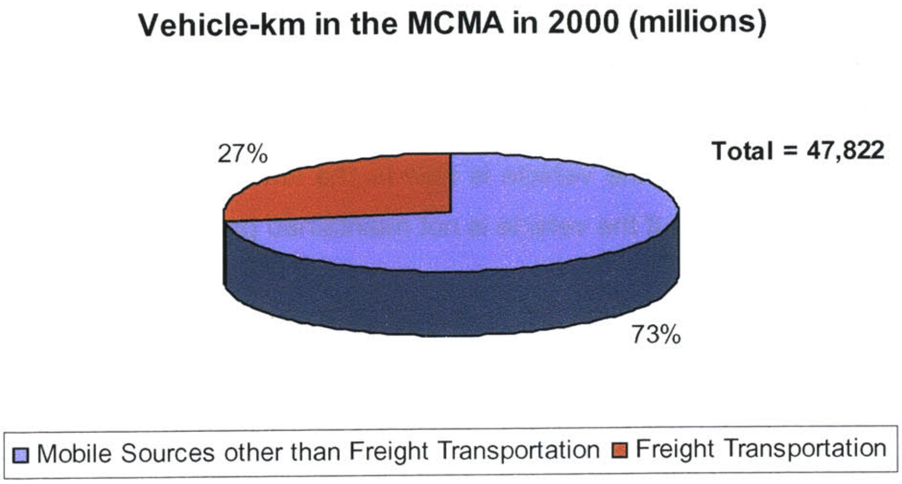
Figures in grams/mile
Source: Environmental Protection Agency
Note: Assuming an annual use of 18,000 miles and regular maintenance.

2.5.3 Freight Transportation Pollutant Emissions in the MCMA

The MCMA's Metropolitan Environmental Commission (CAM[11]) in an effort to quantify pollutant emissions from different sources published a pollutant emissions' inventory in 1998. Such inventory is divided into mobile and non-mobile sources. Mobile sources in turn are divided into passenger transportation and freight transportation. Non-mobile sources include the industrial, commercial and informal sectors, as well as biogenics.

Based on the emissions' inventory, 27% of all vehicle-km in the MCMA are attributable to freight transportation, as seen in figure 2-6.

Figure 2-6 Vehicle-km in the MCMA



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[11] Comisión Ambiental Metropolitana

Even though it only contributes to 27% of all vehicle-km in the MCMA, its contribution to key pollutants is considerably high. As shown in table 2-7 freight transportation emits 25%, 41% and 13% of all PM_{10}, NO_x and NMHC emissions in the MCMA, respectively.

Table 2-7 Freight Transportation Contribution to Pollutants' Emissions in the MCMA

Pollutant Source	**Pollutants (tonnes/year)**		
	PM_{10}	**NO_x**	**NHMC**
Light Duty Gasoline Trucks	183	18,961	24,599
Heavy Duty Gasoline Trucks	84	15,297	18,683
Heavy Duty Diesel Trucks	4,685	50,490	16,960
Natural Gas Trucks	16	308	215
Total Freight Transportation 1/	**4,968**	**85,056**	**60,457**
Passenger Transportation	2,165	80,782	127,316
Non-mobile	12,756	40,047	287,248
Total	**19,889**	**205,885**	**475,021**
Freight transportation contribution (%)	**25%**	**41%**	**13%**

Source: "Programa para Mejorar la Calidad del Aire de la Zona Metropolitana del Valle de México 2002-2010 (PROAIRE)". 1/ Does not include railroad emissions.

It is our belief that emissions related to mobile sources, including freight transportation are not accurately estimated in the Emissions' Inventory. The reason for that is that the vehicle fleet used in their estimates could be overestimated. They estimate that the freight fleet is composed of approximately 600,000 vehicles, which contrasts with our estimate of 436,000 vehicles. Based on data published in SETRAVI (1996) and Rogers (1999), as well as interviews in Mexico City, we believe their estimate of 600,000 vehicles includes freight vehicles that are no longer used in the MCMA. The reason behind is that they used vehicle registration data in their estimates that includes the vehicles that enter the freight fleet, but does not account for vehicles leaving it. In other words, the stock of vehicles included in that data does not have an outflow of vehicles, only an inflow.

Consequently, estimates of the vehicle fleet will have to be overestimated. It has been estimated that their calculations are overestimated by approximately 40%[12].

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[12] Rogers (1999)

By taking this into account, we have estimated that the number of vehicle-km for freight vehicles in year 2000 was 7,000, which would lower its share to 17%, instead of 27%. Meanwhile, its contribution to key pollutants in the MCMA would still be important, but considerably lower than previously estimated. As shown in table 2-8, freight vehicles emitted 1,785 tonnes of PM_{10}, 104,566 tonnes of NO_x and 163,618 tonnes of NMHC in year 2000, which would lower their contribution to 9%, 12% and 8% of all PM_{10}, NO_x and NMHC emissions in the MCMA. However, these contributions may be underestimated if we consider that other mobile sources might be overestimated for similar reasons than the ones explained above.

Table 2-8 Freight Transportation Contribution to Pollutants' Emissions in the MCMA

Pollutant Source	**Pollutants (tonnes/year)**		
	PM_{10}	**NO_x**	**NHMC**
Light-Duty Gasoline Vehicles	101	4,627	18,482
Heavy-Duty Gasoline Vehicles	57	3,457	10,626
Heavy-Duty Diesel Vehicles	1,626	15,599	7,108
Light-Duty Natural Gas Vehicles	2	101	87
Total Freight Transportation [1/]	**1,785**	**23,784**	**36,302**
Passenger Transportation	2,165	80,782	127,316
Non-mobile sources	12,756	40,047	287,248
Total	**3,950**	**104,566**	**163,618**
Freight transportation contribution (%)	**9%**	**12%**	**8%**

Source: Estimations based on figures Publisher in SETRAVI (1996) and "Programa para Mejorar la Calidad del Aire de la Zona Metropolitana del Valle de México 2002-2010 (PROAIRE)". 1/ Does not include railroad emissions.

Table 2-8 shows pollutant emissions' of all road based freight vehicles. Recalling that vehicle type was our first segmentation criterion, we can determine the contribution of each segment under this criterion. Within freight transportation PM_{10} and NO_x emissions are mostly attributable to diesel powered vehicles (91% and 66%, respectively), while NHMC emissions to gasoline powered vehicles (80%).

Using our second segmentation criterion, the type of movement, we can determine the contribution of the local, out of region and drive through freight transportation segments. As shown in table 2-9, the local freight segment contributes the most to all pollutant emissions. This seems reasonable since this segment includes most of the freight vehicles in the MCMA.

Table 2-9 Local, Out of Region and Drive through Freight Transportation Segments Contribution to Pollutants' Emissions in the MCMA

Pollutant Source	Pollutants (tones/year)		
	PM_{10}	NO_x	NHMC
Local Freight Segment	1,178	16,411	31,220
Out of Region Freight Segment	553	6,660	4,719
Drive through Segment	54	714	363
Total Freight	**1,785**	**23,784**	**36,302**

Source: Estimated using data presented in SETRAVI (1996) and "Programa para Mejorar la Calidad del Aire de la Zona Metropolitana del Valle de México 2002-2010 (PROAIRE)".

The emissions' inventory data does not allow us to distinguish between pollutant emissions from the for hire and privately owned fleets, our third segmentation criterion.

2.6 Stakeholders in the Freight Transportation System

The freight transportation system in the MCMA, given its characteristics, includes a diverse set of stakeholders. These stakeholders and their interests must be kept in mind throughout the analysis of the system. We have identified the following key stakeholders in the MCMA's freight transportation system:

1. General Population
2. Freight Customers
3. Institutional Stakeholders:
    a. Metropolitan Environmental Commission (CAM)
    b. Government of the Distrito Federal (DF)
    c. Government of the Estado de México
    d. Municipal Governments in the EM
    e. National Chamber of Freight Transportation Companies
    f. Private Companies' National Chambers.

General Population: The MCMA's population will be affected by nearly all decisions made regarding freight transportation. Within the general population, the drivers using the MCMA's road networks are affected daily by the freight vehicles circulating in it. Furthermore, freight vehicles' emissions affect their health.

Freight Customers: freight customers will also be affected by nearly any decision made regarding freight transportation. Freight transportation strategies aimed towards reducing pollutant emissions that raise costs considerably might affect them negatively since such costs could increase the prices offered to them by freight companies. Therefore, even though a more efficient and viable freight transportation system in the MCMA could be in the city's best interest, measures that raise costs that will eventually be passed on to customers might not be backed by these stakeholders.

Metropolitan Environmental Commission (CAM): The CAM was created by the Federal government, the Distrito Federal (DF) Government and the Estado de México (EM) Government. It is responsible for "defining and coordinating policies, programs, projects and actions related to the protection of the environment, its preservation and restoration of the ecological equilibrium in the Mexico City Metropolitan Area". The Presidency of the Commission rotates every two years between the Major of the DF and the Governor of the EM. Even though the CAM was created by Federal and Local Governments, it lacks the legal power to enforce the compliance of programs and policies related to the protection of the environment, including air quality.

Government of the Distrito Federal (DF): Most transportation regulations, programs and policies, including freight transportation, within the government of the DF are handled by the Secretary of Transportation called SETRAVI[13]. This agency is not only responsible for regulating and devising plans and policies for freight transportation, but is also legally capable of enforcing policies and implementing plans within the DF. Since Mexico City includes both the DF and the EM, SETRAVI officials must often coordinate with government officials from the Estado de México's Ministry of Transportation to coordinate programs and policies that include both states.

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[13] Secretaria de Transporte y Vialidad

Government of the Estado de México: Just as with the Government of the DF, the Secretary of Transportation of the Estado de México is responsible of transportation regulations, programs and policies in the EM. This agency also has the legal capacity to enforce policies and implement plans within the EM. As mentioned above, both Transportation Agencies must coordinate their efforts to enforce and implement policies and programs that include both states.

Municipal Governments in the EM: The Estado de Mexico is divided into municipalities, some of which are included in the MCMA. These municipalities have the legal capacity to carry out actions related to freight transportation in their jurisdiction. Thus, government officials from the EM and DF must include them in the planning of freight transportation in the MCMA.

National Chamber of Freight Transportation Companies (CANACAR[14]): The CANACAR is the only freight transportation association in Mexico. This Chamber offers technical and advice to freight transportation companies. Most importantly, the Chamber lobbies with the government in favor of the interests of its members. It has a considerable influence in policies related to freight transportation in Mexico.

Private Companies National Chambers (CANACINTRA[15]): These chambers include many private companies from the MCMA and the entire nation. Some of these chambers include several of the most important companies in Mexico, thus their political influence in government decisions, including freight transportation, is considerable.

2.7 Key Findings

In this chapter we have analyzed the composition of the freight transportation system in the MCMA. We have segmented the vehicle fleet with respect to the type of vehicle used, the type of movement performed by them, as well as the fleet ownership.

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[14] Cámara Nacional de Autotransporte de Carga

[15] Cámara Nacional de la Industria de la Transformación

We have seen that light-duty gasoline vehicles compose most of the freight fleet (58%). Likewise, the local public fleet has the highest number of vehicles (79% of the total freight vehicle fleet). Furthermore, the vehicle freight fleet can be considered as relatively old. For instance, the out of region for hire fleet has an average age of 18 years old.

Freight vehicles' contribution to key pollutant emissions is important. We have estimated that freight vehicles' contribution to PM_{10}, NO_x and NMHC emissions in the MCMA is 9%, 12% and 8% of all emissions, respectively.

Finally, we have identified a series of stakeholders involved in the MCMA's freight transportation system. These stakeholders and their interests must be kept in mind throughout the analysis of the system.

Having analyzed the MCMA's freight transportation system we can now move on to estimating future freight transportation demand for the city, as well as its emissions of key pollutants. Furthermore, this analysis will help us define strategies related to freight transportation aimed towards improving air quality in the MCMA.

CHAPTER 3: MODELING FREIGHT TRANSPORTATION DEMAND, EMISSIONS AND COSTS

3.1 Introduction

This chapter describes a modeling method to quantify freight transportation demand, its contribution to key pollutant emissions, as well as the costs of the MCMA freight fleet. The structure of the model, the assumptions used in it, its results and limitations are also discussed.

This chapter also includes a description of scenario planning as a tool for planning under uncertainty. The construction of scenarios and their relationship to freight transportation are also discussed and analyzed.

3.2 Scenario Planning and Future Stories

In Chapter Two we analyzed the freight transportation system in the MCMA, its composition and main characteristics. We saw that even though it is necessary for the economic growth of the region, its contribution to pollutant emissions in the MCMA is substantial; thus it is desirable to reduce its negative impacts on the city.

In order to improve the freight transportation system in the MCMA it is necessary to develop strategies to be implemented sometime in the future. Such strategies must evaluated to asses their potential benefits and negative effects. Since it is possible to develop more than one strategy, it is also necessary to compare the performance of different strategies to be able to determine which ones should be implemented in the MCMA.

The evaluation of transportation-related strategies is usually associated with a relatively long planning horizon. In the case of the Mexico City Project[16] the planning horizon covers twenty five years (2000-2025). These long planning horizons have associated great uncertainties with respect to the behavior of system and its components, which can negatively impact the outcome of any strategy that is implemented. For instance, if the actual economic growth of the city throughout the planning horizon is considerably different than originally estimated, it could be possible that any strategy based on the original estimate might fail to reach its objective or even have a counter effect. If we consider that transportation related decisions usually have substantial economic impacts and involve considerable financial investments, it is important to handle these great uncertainties properly.

In order to deal with these uncertainties, for the development and analysis of freight transportation strategies for the MCMA we use a planning method called scenario planning.

Scenario planning is an approach to planning whose origins can be traced back to the Royal Dutch Shell Company. Shell began using this approach in the early 1970's as a result of an internal effort to develop a planning approach that could better deal with uncertainty, covering a "wide span of possible futures". Scenario analysis proved to be very helpful to Shell, and its application eventually enabled it to anticipate and prepare for the oil crisis of 1973 (Wack, 1985).

Scenario planning calls for the construction of a series of scenarios or possible futures to be used in the planning process. These scenarios should include elements that are important drivers of a system, as well as being inherently uncertain. As mentioned by Zegras et al. (2002), the potential value of scenario planning lies in its providing a coherent and systematic framework for assessing long-term effects of changes in key influencing factors. Furthermore, scenario planning can help us better deal with uncertainty by avoiding planning for a single future; instead we develop several possible futures and plan for them[17]

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[16] Refers to the MIT Integrated Program on Urban, Regional and Global Air Pollution: Mexico City Case Study

[17] Zegras et al. (2002)

The potential value of scenario planning lies in its providing a coherent and systematic framework for assessing the long-term effects of changes in key influencing factors. As mentioned by Zegras et al. (2002) "scenario planning can potentially offer a means to avoid planning for a single forecasted future by enabling the coherent development of several possible futures and plan for them". Simply put, scenario planning helps to make robust strategic choices[18].

3.2.1 Scenario Analysis and Future Stories for the MCMA

The scenarios constructed for the Mexico City Project[19] were intended to be used not only for the freight transportation system, but also for other important systems in the MCMA. They include:

1) The passenger transportation system (public transportation and private automobiles).
2) The industrial and commercial sectors (formal and informal).
3) The household sector

Three different scenarios labeled as "future stories" were constructed. They were labeled as "future stories" because they present a coherent and logic story of the future development and behavior of the MCMA. These future stories have been named 1) "A Divided City"; 2) "Changing Climates"; and 3) "Growth Unbound".

The elements included in these future stories were chosen to include the variables considered to be relevant and presented a considerable level of uncertainty with respect to its future behavior. Freight transportation is affected primarily by four driving forces included in these future stories: 1) Economy; 2) Population; 3) Urban Form; 4) Politics.

All these driving forces will impact the freight transportation system. Such impact can be assessed quantitatively or qualitatively. The impact of the first three driving forces

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[18] Zegras et al. (2002)
[19] These scenarios were constructed by Rebecca Dodder.

(economy, population and urban form) can be estimated quantitatively, while the impact of the last one (politics) is assessed qualitatively, as seen in table 3-1.

Table 3.1 Driving Forces of Future Stories and Freight Transportation

Main Driving Forces	**Future Stories**			**Link To Freight Transportation**
	"A Divided City"	**"Changing Climates"**	**"Growth Unbound"**	
1. Economy	• GDP: 3.1% annual growth. • Industrial. Output: 2.3% annual growth.	• GDP: 3.7% annual growth. • Industrial. Output: 2.6% annual growth.	• GDP: 5.0% annual growth. • Industrial. Output: 4.9% annual growth.	Quantitative
2. Population	High: 1.5% annual growth.	Moderate: 1.2% annual growth.	Low: 0.8% annual growth.	
3. Urban Form	Sprawl and expansion of the city.	Consolidation and densification.	Suburban growth and densification.	
4. Politics	• Moderate government intervention in investment and enforcement. • High level of corruption high.	• High government intervention in investment and enforcement. • Low level of corruption.	• Medium government intervention in investment and enforcement. • High level of corruption.	Qualitative

Economy: one of the main drivers behind the demand for freight transportation is economic growth. More specifically, the industrial output of a region is closely related to its demand for freight transportation. Usually, a growth in the industrial output of a region will cause a growth in freight transportation demand; thus, the economic growth of the region will influence the demand for freight transportation and consequently the number of freight-related pollutant emissions in the MCMA.

Population: this is also a key driver of freight transportation demand. A region's population will ultimately consume a portion of the goods produced in the region or outside of it. As population increases in a region so does the demand for goods and consequently for freight transportation. This in turn will influence the number of pollutant emissions in the region.

Urban form: The form of the MCMA will directly influence the distance traveled by freight vehicles in it. Usually, freight vehicles will travel longer distances in a sprawling metropolitan area than a compact one.

Politics: the political structure in the MCMA can have a considerable effect on freight transportation. The political characteristics of the governments in the MCMA (the DF and the EM and the Federal government) will influence the level of cooperation and collaboration in the implementation of any freight-related strategy proposed. Likewise, the level of government enforcement of any freight-related strategy proposed will influence its success or failure.

All freight strategies developed should be tested against the three different future stories when estimating their performance. By doing this, we can assess each strategy's "robustness" with respect to the uncertainty posed by the key drivers included in the future stories. In general, a strategy with good performance under all future stories can be considered more "robust" than another with good performance under one or two future stories.

Having specified the different scenarios (future stories) considered, as well as their main driving forces we can move on to modeling freight transportation and pollutant emissions in the MCMA.

3.3 Model Description

3.3.1 Background

Even though passenger transportation modeling has reached a certain level of maturity, freight transportation can be considered to be at an earlier stage of development. Within freight transportation, urban freight transport models are the least developed[20]. These models are usually based on vehicles movements within a city instead of on the goods

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[20] Garrido (2002)

they carry. Furthermore, passenger transportation modeling techniques are often used as a basis for their development. The traditional four step planning process used for passenger transportation (trip generation, trip distribution, modal split and traffic assignment) is frequently applied in freight transportation modeling. This approach has been criticized for not reflecting the actual phenomenon taking place in freight movements[21].

The output of urban freight transportation models usually includes freight vehicle flows within the city, which in turn can be used to predict vehicle emissions in a region.

As mentioned in Chapter One, our research involves the estimation of future freight transportation and its impact on emissions. However, it also includes the estimation of economic and financial costs associated with the freight fleet in the MCMA. When evaluating any freight-related strategy it is necessary not only to assess its capability of improving air quality, but also to determine what will be the costs associated with it. By including this evaluation criterion we can better compare freight strategies since the most desired strategy might no longer be the one that best improves air quality, but also the one which does so in the least costly manner.

Based on the data available and our understanding of the freight transportation system in the MCMA we have developed a deterministic vehicle-based model that links freight transportation, pollutant emissions and economic and financial costs of the freight fleet.

The model requires data of socioeconomic variables in the MCMA, its freight fleet composition and, environmental parameters and cost variables. The model we present in this thesis is:

1. A deterministic vehicle-based freight demand-environmental emissions-financial and economic costs model that can be used for evaluating the benefits (pollutant emissions reductions) and financial and economic costs of various freight-related strategies to improve air quality in an urban area.

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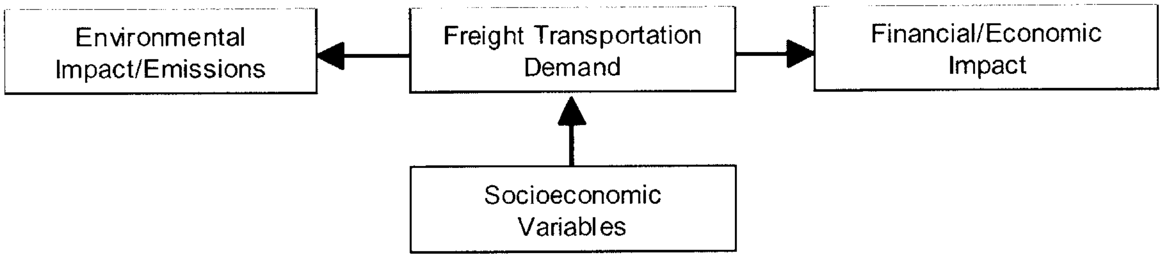
[21] See Garrido (2002) for a detailed discussion regarding the setbacks of applying the four step planning process to freight transportation.

2. A tool that can be improved incrementally through the use of better data and methods.

The model framework is shown in figure 3-1. Socioeconomic variables (i.e. population and economic growth) of the region are the basis for the demand for freight transportation, which in turn is used to estimate the environmental impact (vehicle emissions) and financial and economic costs of the freight fleet in the MCMA.

Figure 3-1 Model Framework



The main inputs and outputs of the model we are using are presented in figure 3-2. Socioeconomic, freight vehicle, environmental and cost parameters are used to calculate freight transportation demand, emissions and fuel consumption of freight vehicles as well as economic and financial costs.

Figure 3-2 Model Inputs and Output

Inputs

I. Socioeconomic Parameters
- a. Economic growth (Industrial Output)
- b. Population
- c. Urban Form

I. Freight Vehicle Parameters
- a. Vehicle usage per vehicle type (i.e. average daily trips, average km per trip)
- b. Empty trips per vehicle type
- c. Freight composition and distribution
- d. Vehicle capacity per vehicle type
- e. Average capacity utilization per vehicle type
- f. Survival rate per vehicle type

II. Environmental Parameters
- a. Emission factors per vehicle type and per pollutant
- b. Fuel efficiency per vehicle type

III. Cost Parameters
- a. Labor wages
- b. Prices (i.e. vehicle, energy)
- c. Other costs (i.e. government fees, insurance)
- d. Inflation
- e. Risk free rate

Outputs

I. Freight Transportation Demand
- a. Annual vehicle-km per vehicle type
- b. Total annual vehicle-km

II. Environmental
- a. Total emissions by vehicle type and pollutant
- b. Total energy consumption

III. Costs
- a. Annual economic and financial costs (i.e. capital, energy, labor)
- b. Present Value of Total Costs

3.3.2 Major Assumptions

Freight Demand

The estimation of freight transportation demand in the MCMA, measured in vehicle-km, is made in two steps. First, the demand for goods that will be moved within the city is estimated. Second, the distances that these goods will travel within the MCMA are calculated. The number of goods to be moved in the MCMA is determined by two factors: 1) economic growth in the region; more specifically, industrial output of the MCMA; and 2) population of the MCMA.

The distances that vehicles transporting these goods will travel within the MCMA are estimated based on the urban form of the city. The relationship between industrial output growth, as well as population growth, and growth in goods demanded in a region was based on data from the cities of Santiago, Chile and Sao Paulo, Brazil[22]. The relationship between the urban form of the city and the average distance traveled by freight vehicles has been estimated from data included in SETRAVI (1996).

Freight Vehicle Composition in the MCMA

In Chapter Two we analyzed the current freight vehicle composition in the MCMA, as well as its main characteristics (i.e. light-duty gasoline vehicles, heavy-duty diesel vehicles, etc.). In order to determine the total impact of freight vehicles on the environment, it is necessary to estimate what will be the freight vehicle composition in the MCMA in future years. Such composition will depend on the future behavior of the region and its components. For instance, future manufacturing and distribution developments may force companies to purchase a greater number of light-duty vehicles instead of heavy-duty vehicles, which would change the freight vehicle composition. Ideally, we would like to have the freight vehicle composition in the MCMA as an endogenous variable in our model. That way, we could test with greater precision the effect of policies that affect freight vehicles operations; however, in order to have it as an endogenous variable we would need a considerable number of data regarding the behavior of freight vehicle owners that is not available[23]. Currently, the freight vehicle composition in the MCMA is an exogenous variable in this model.

Vehicle Capacity and Capacity Utilization

The capacity of a vehicle and its capacity utilization will determine the number of vehicles that are needed to fulfill the demand for goods to be transported in the MCMA. The estimates we use for these variables are taken from SETAVI (1996) and are shown in Chapter Two. It is worth mentioning that the data we are using measures capacity in terms of a vehicle's weight without taking into account its volume capacity. This can

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[22] Secretaria de Economia.

[23] It could be possible to use behavioral models, such as Multinomial Logit and Nested Logit, to estimate the freight fleet composition based on a series of attributes of the different freight vehicles and their users (owners).

prove to be incorrect since a vehicle's capacity might be constrained by its volume and not necessarily by its weight[24]. We address specific issues related to this source of error later on in Chapter Six.

Annual Vehicle Utilization

The annual utilization (operating days per year) of freight vehicles in the MCMA is based on data from SETRAVI (1996) and "Programa para Mejorar la Calidad del Aire de la Zona Metropolitana del Valle de Mexico 2002-2010 (PROAIRE)".

Vehicles Entering and Leaving the Freight Fleet

In the model we have assumed that vehicles leave the freight fleet based on a vehicle's survival and scrappage rate function. This function estimates the percentage of the total number of vehicles in a model year that will be in use at the end of a given year. The vehicle survival and scrappage rate functions used were estimated based on data published on the "Transportation Energy Data Book". Figure 3-3 shows the vehicle survival and scrappage functions used for light-duty vehicles and heavy-duty vehicles in the MCMA.

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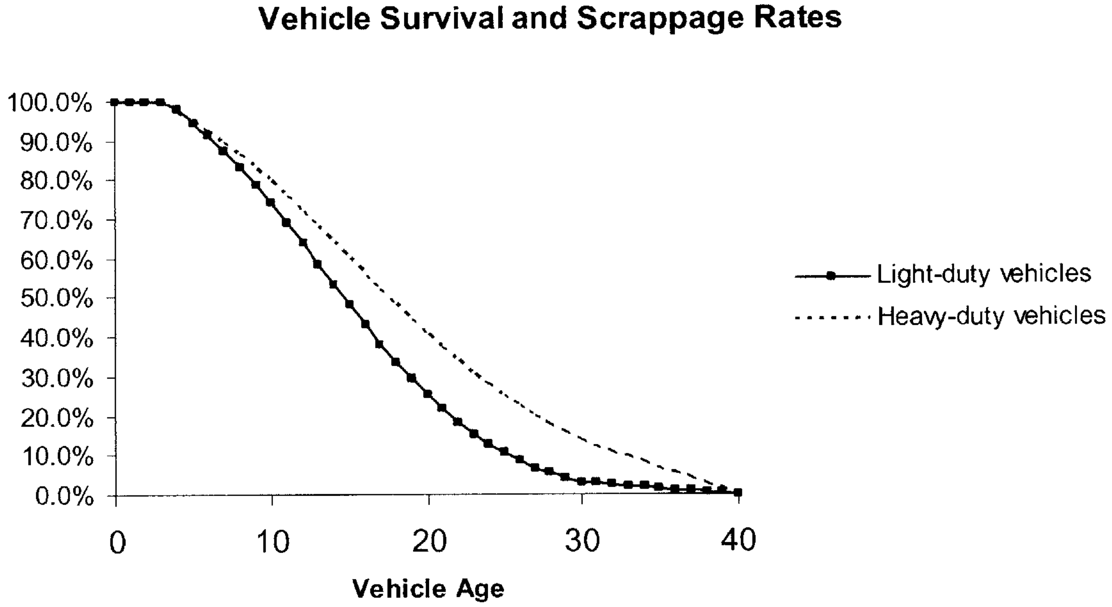
[24] This is especially true for products with a low density (tonnes/m^3).

Figure 3-3 Light-Duty and Heavy-Duty Vehicles' Survival and Scrappage Functions



Note: Survival and Scrappage rate is the percentage of the total number vehicles in a model year that will be in use at the end of a given year

In the model, vehicles enter the MCMA freight fleet either to replace vehicles that leave the fleet or to meet an increase in demand. The age distribution of the vehicles entering the freight fleet is chosen in such a way to maintain the average age constant. For instance, if the average age of the light-duty gasoline vehicle fleet in the MCMA is 15 years in year 2005, then the model years of light-duty gasoline vehicles entering the freight fleet in 2006 is chosen in such a way as to maintain an average age of 15 years for light-duty gasoline vehicles in year 2006.

Vehicle Emissions

There are multiple components of vehicle emissions. The largest share of vehicle emissions is "tailpipe" or exhaust emissions[25]; however, evaporative emissions or refueling losses can also be significant. As mentioned in Chapter Two, vehicle emission rates depend on a series of factors, including the type of fuel used by the vehicle, its engine characteristics, the driving cycle, and its age.

In our model we use vehicle emission rates that were calculated using one of the most widely used emissions model in the world, MOBILE. This model was created by the U.S. EPA and MOBILE version 5 was applied to the Mexico City vehicle fleet[26]. The inputs to the MOBILE model include vehicle type, type of fuel used, model year of the vehicle, average speed, operating mode (i.e. driving cycle), emissions control technologies, vehicle load factors, inspection and maintenance parameters, altitude and air temperature. The outputs of MOBILE are exhaust emission factors measured in grams per distance traveled[27]. These emission factors are specified per pollutant type and vehicle type. Furthermore, they are disaggregated by model year. The values of the emission factors used in the model are the ones published in PROAIRE 1998.

Vehicle Fuel Efficiency

The fuel efficiency of vehicles will determine the number of energy sources consumed, as well as the level of pollutant emissions. In the model we use fuel efficiency factors (miles/gallon) published by the Environmental Protection Agency. The values of freight vehicles' fuel efficiency factors are included in Appendix.

Future Vehicle Emission Factors and Fuel Efficiency

The model we present will be used to estimate future emissions through 2025. Therefore, it is necessary to know not only the emission factors and fuel efficiency of vehicles currently circulating in the MCMA, but also for vehicles that will be entering the

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[25] Environmental Protection Agency (1994)
[26] PROAIRE (2002)
[27] Environmental Protection Agency (1994)

freight fleet in future years. Estimating future emission rates and fuel efficiency is certainly not an easy task if we consider all the uncertainties related to them.

To estimate these parameters we based our analysis on their historical behavior. Based on such behavior we have assumed that emission rates and fuel efficiency improvements are driven mainly by government regulations. Figure 3-4 shows the fuel efficiency of new heavy gasoline trucks from 1980-1998. The figure clearly illustrates that fuel efficiency has practically remained constant during the 18 years analyzed. During this period, there were no regulations aimed towards this type of vehicle, enforcing an increase in fuel efficiency.

Figure 3-4 Fuel Efficiency Evolution of New Heavy Gasoline Trucks (1980-1998)

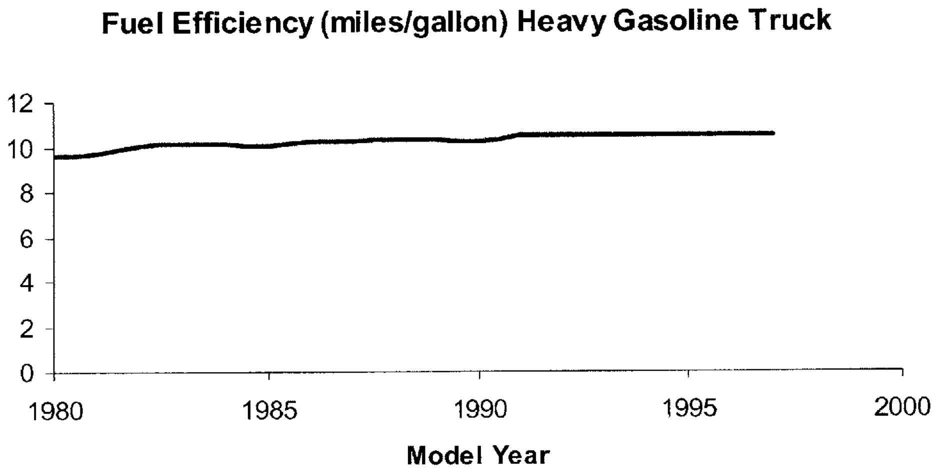


Figure 3-5 shows a similar evolution for emission rates of a key pollutant (CO). It illustrates how emission rates slightly decreased from 1980 to 1985, but practically remained constant from 1985 to 2000. Again, the main reason for this is the lack of government regulations aimed towards reducing emission rates for this pollutant and this type of vehicle.

Figure 3-5 CO Emission rates of New Heavy Duty Diesel Powered Vehicles (1980-2000)

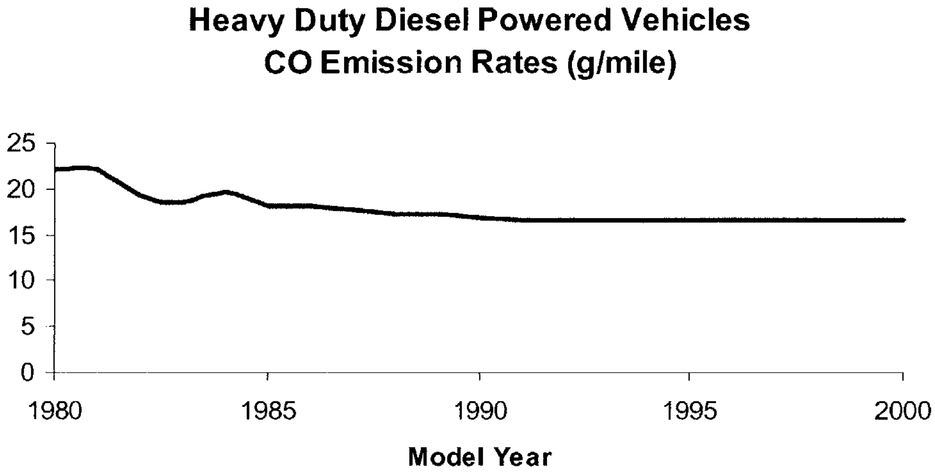
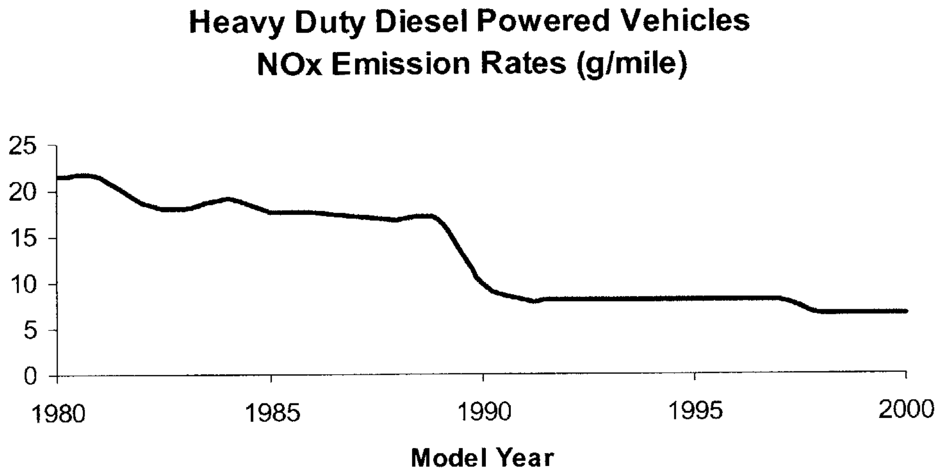


Figure 3-6 shows the evolution of NO_x emission rates for new vehicles from 1980 to 2000. In it we can see that there are two major emission reductions. The first one, in the period 1989-1990, represents a 41% reduction, from 16.77 to 9.87 grams/mile. The second one, in the period 1997-998, represents a 20% reduction, from 8.13 to 6.49 grams/mile. Both of these improvements are the result of stricter government regulations, specifically from the Environmental Protection Agency (EPA), for this type of pollutant and this type of vehicle.

Figure 3-6 NO_x Emission rates of New Heavy Duty Diesel Powered Vehicles (1980-2000)



Based on these figures, and the fact that Mexican emissions and fuel efficiency standards are based EPA regulations, it is reasonable to assume that any improvements in emissions or fuel efficiency will be driven by government regulations.

In our model government regulations is not an endogenous variable. In fact, to model a significant increase in fuel efficiency or decrease in emissions rate, it would be necessary to introduce an exogenous variable that modifies these parameters. In other words, no major improvements in both fuel efficiency and emission rates would be considered when evaluating a "business as usual" situation. Since the audience to whom the model results will be presented include government officials, it seems reasonable to show them how future emissions' levels will behave if no regulations are approved and implemented.

An alternative approach would be to predict fuel efficiency improvements, as well as reduced emission rates for future years; however, this approach would present major problems, such as:

1) It would be necessary to model the process behind government regulations for future years; i.e. what will be the content of those regulations, when will they be implemented, what will be their deployment schedules, etc.

2) A scenario of "business as usual" could be too optimistic if any regulatory effects are included, even though they may never occur. Thus, government official could underestimate future emission levels.

Cost components and assumptions

Within the cost segment of our model, we include the following categories[28]:

1) *Capital costs*: includes the costs of new and used vehicles that enter the freight fleet. It also includes any capital costs related to the strategies aimed towards improving air quality in the MCMA. For instance, a strategy that calls for the retrofitting of freight vehicles would have retrofit devices installed on vehicles. The costs of these devices would be included in this category. The costs of new and used vehicles were estimated based on real data from Mexico City[29]. Their future values were estimated using the annual inflation rate for the MCMA.

2) *Energy costs*: includes the costs of the gasoline, diesel and natural gas consumed by freight vehicles. Furthermore, it also includes the costs of lubricants used by these vehicles. Future fuel costs depend on the fuel quality of the gasoline and diesel offered in the MCMA, as well as the international oil prices. Future values of energy prices are shown in Appendix.

3) *Labor costs*: includes the costs of workers in the freight fleet in the MCMA. More specifically, it includes vehicle drivers and maintenance workers wages. The wages of drivers and maintenance workers were calculated using labor related data for the MCMA[30]. Future wages were estimated to grow with inflation. The number of maintenance time a vehicle needs per year is a function of the vehicle's age. The estimation of this parameter was based on a World Bank study of vehicle operating costs in developing countries[31].

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[28] The costs components of our model only include the costs associated with the road based freight fleet; thus, we are not including the costs associated with the railroad.

[29] www.reforma.com; www.segundamano.com.mx

[30] Secretaria del Trabajo (2002).

[31] Vehicle Operating Costs (VOC) World Bank (1995)

4) *Maintenance costs*: includes the costs related to maintenance parts as well as tires. Maintenance parts are calculated as a fraction of the cost of the vehicle. These costs depend on the age of the vehicle and were based on the World Bank study of vehicle operating costs on developing countries[32]. The costs of tires were based on data for Mexico City. Their average lifetime was assumed to be 100,000 km based on tire manufacturer's guarantees.

5) *Government fees*: includes fees related to the ownership of vehicles in the MCMA. More specifically, they include a vehicle ownership fee called "tenencia". This is an annual fee that depends on the vehicle type, its age and its usage (i.e. personal or commercial), which must be paid every year by vehicle owners. These fees were assumed to grow with inflation.

6) *Insurance costs*: includes the insurance costs of vehicles in the MCMA. These costs were estimated based on market values for the MCMA[33]. These costs depend on the vehicle's age and were assumed to grow with inflation.

7) *Corporate overhead costs*: includes costs related to the ownership of freight vehicles. These costs include administrative and other overhead costs of companies or individuals that own freight vehicles. They were estimated to be 20% percentage of annual fixed costs (labor, insurance and government fees)[34].

8) *Air quality strategy enforcement and implementation costs*: these costs are specific to any strategy that will be tested using our model. For instance, a strategy that calls for the retrofitting of freight vehicles circulating in the MCMA would have implementation associated with it, such as workers that install these devices and enforcement agents (i.e. policemen) that make sure that the vehicles using the road network have retrofit devices.

The costs included in these categories are summed up to get the annual total costs of the MCMA freight fleet. The annual costs of each year are presented in nominal pesos,

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[32] Vehicle Operating Costs (VOC) World Bank (1995)
[33] Grupo Nacional Provincial (2002)
[34] Based on methodology presented in SETRAVI (2000)

not in constant pesos because these results will be presented to Mexican decision-makers who will find it is useful to know what the costs will be in future years when implementing a strategy.

The annual costs estimated for all years in the planning horizon (2000-2025) are then discounted to the base year (2000) in order to get the present value of the total costs of the MCMA. The discount rates used are calculated as the inflation rate plus the social risk free rate. Since each future story has a different inflation rate, the discount rate will be different for each one of them.

3.4 Model Development

3.4.1 Flow Diagram

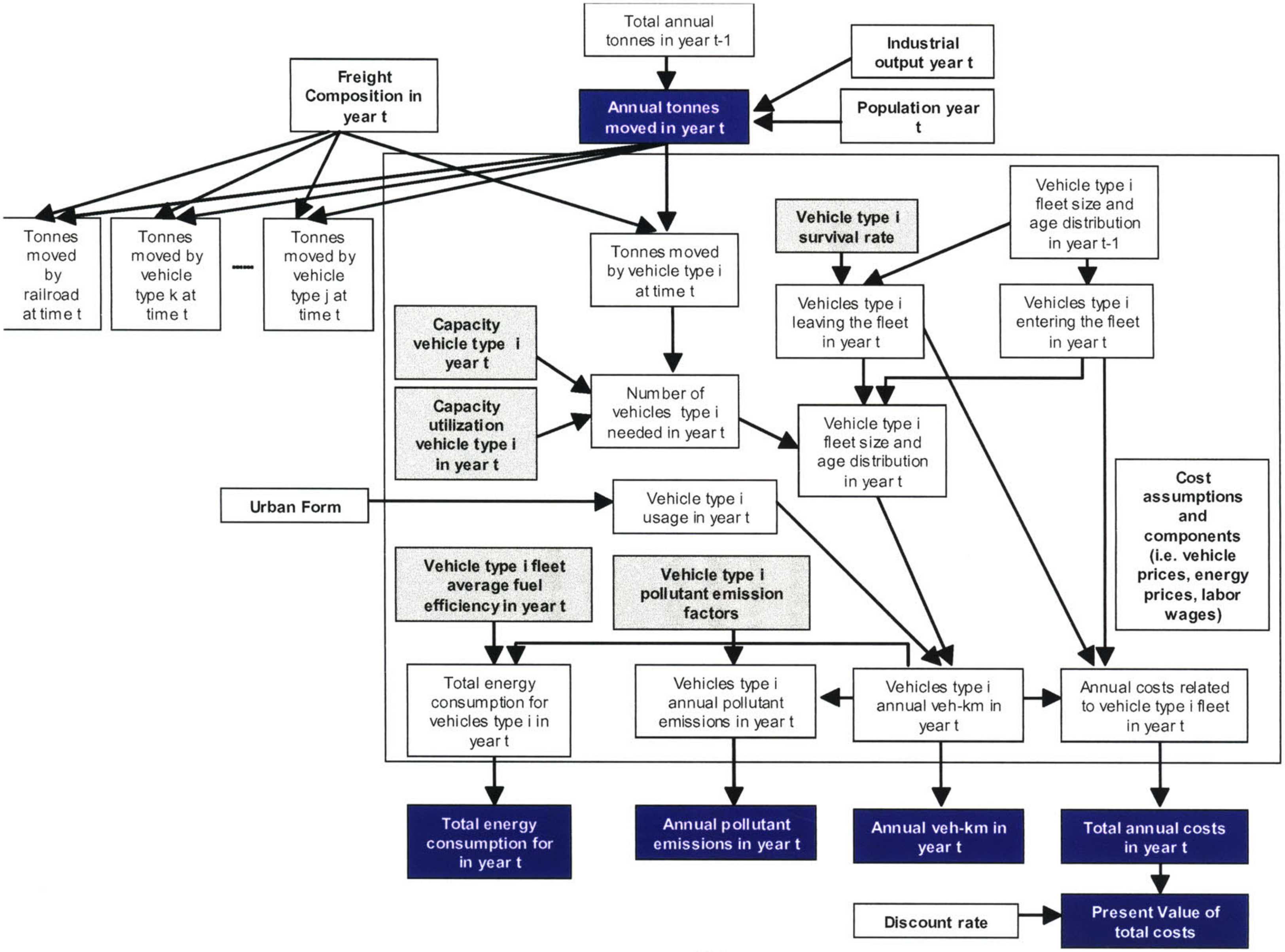
Figure 3-4 is a flow chart of the model we are using. The shaded boxes are empirical data gathered from the various sources described earlier. The dark boxes are model results. They include:

1) *Freight Demand:* a) the total number of annual tonnes moved in the MCMA; b) Total annual vehicle-km in the MCMA.

2) *Environmental:* a) Total emissions per pollutant; b) Total annual fuel consumption.

3) *Economic and Financial Costs*: a) Total annual costs of the MCMA freight fleet; b) Present value of total costs of the MCMA freight fleet.

Figure 3-7 Model Flow Diagram



3.4.2 Model's Initial Conditions

In order to run our model, it is necessary to have an estimate of the total number of goods to be moved in the MCMA in the first year (2000), which we can calculate using the following equations[35]:

$$D_i = C_i * CU_i * NV_i * O_i$$

$$D = \sum_i D_i + D_{railroad}$$

Where,

D = total annual tonnes moved in the MCMA.

D_i = annual tonnes of goods moved by vehicle type i

$D_{railroad}$ = annual tonnes of goods entering or leaving the MCMA moved by the railroad

C_i= average tonne capacity of vehicle type i

CU_i = average capacity utilization

NV_i = number of vehicles type i in the MCMA freight fleet

O_i = Number of operating days per year for vehicle type i

By applying these two equations, we get that the total number of goods moved in the MCMA for year 2000 was approximately 500 million tonnes, as shown in table 3-2.

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[35] Based on the methodology presented in SETRAVI (1996)

Table 3-2 Annual tonnes of goods moved in the MCMA in Year 2000 by Vehicle Type

Vehicle Type	Annual Tonnes of Goods Moved in the MCMA (thousands)	Percentage of Total Goods Moved in the MCMA
Light-Duty Gasoline Trucks	40,960	8.1%
Heavy-Duty Gasoline Trucks	126,365	25.1%
Heavy-Duty Diesel Trucks	321,147	63.9%
Light-Duty Natural Gas Trucks	2,831	0.6%
Railroad	11,500	2.2%
Total	**502,803**	**100%**

3.4.3 Pollutant Emissions Estimates

The annual pollutant emissions for freight vehicles are estimated using the following equations:

$$E_{imj} = \left(NV_{im} * AT_{im} * EF_{imj}\right) * 10^{-6}$$

$$E_j = \sum_i \sum_m E_{imj}$$

Where:

E_j = annual emissions of pollutant j (tonnes/year)

E_{imj} = annual emissions by vehicle type i, model year m of pollutant j (tonnes/year)

NV_{im} = number of vehicles type i, model year m

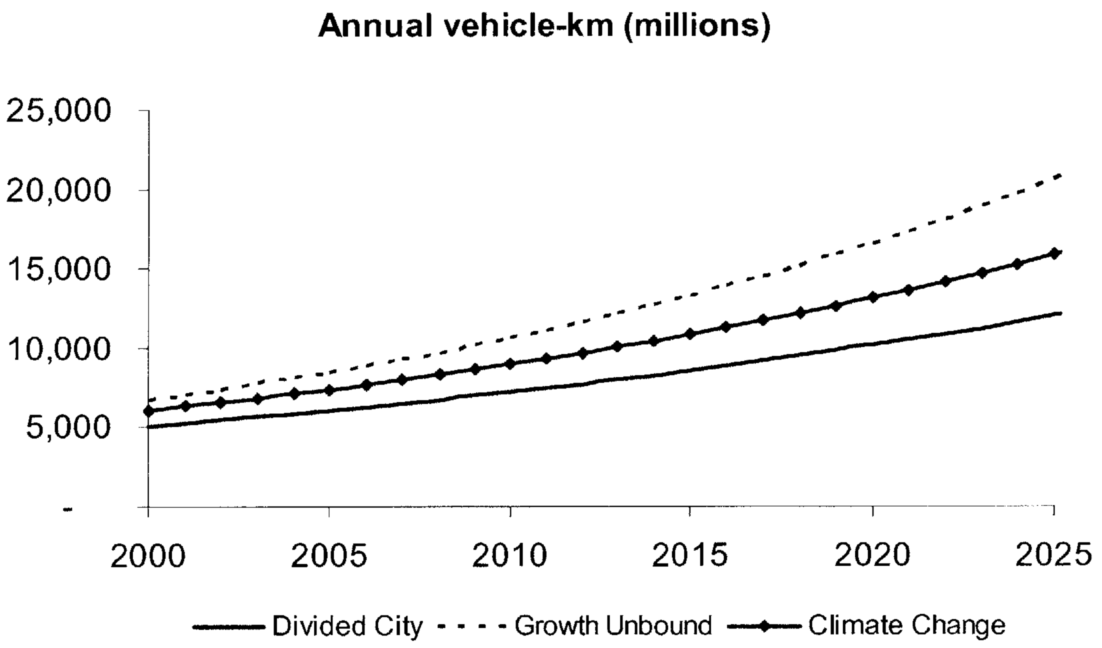
AT_{im} = average annual kilometers traveled by vehicle type i, model year m

EF_{imj} = emission factor for vehicle type i, model year m of pollutant j (grams/veh-km)

3.5 Model Calculations

Having specified the model and its initial conditions we can use it to estimate future transportation demand, pollutant emissions and costs for the MCMA freight fleet. Figures 3-8 through 3-12 show the main results of the model for all three future stories.

Figure 3-8 Freight Transportation Demand for the MCMA



From this figure we can note that freight transportation demand in the MCMA, measured vehicle-km, would keep increasing under all future stories driven by economic growth. By year 2025, it would range between 13,000 and 23,000 million vehicle-km depending on the future story.

Figure 3-9 Freight Transportation NMHC Pollutant Emissions

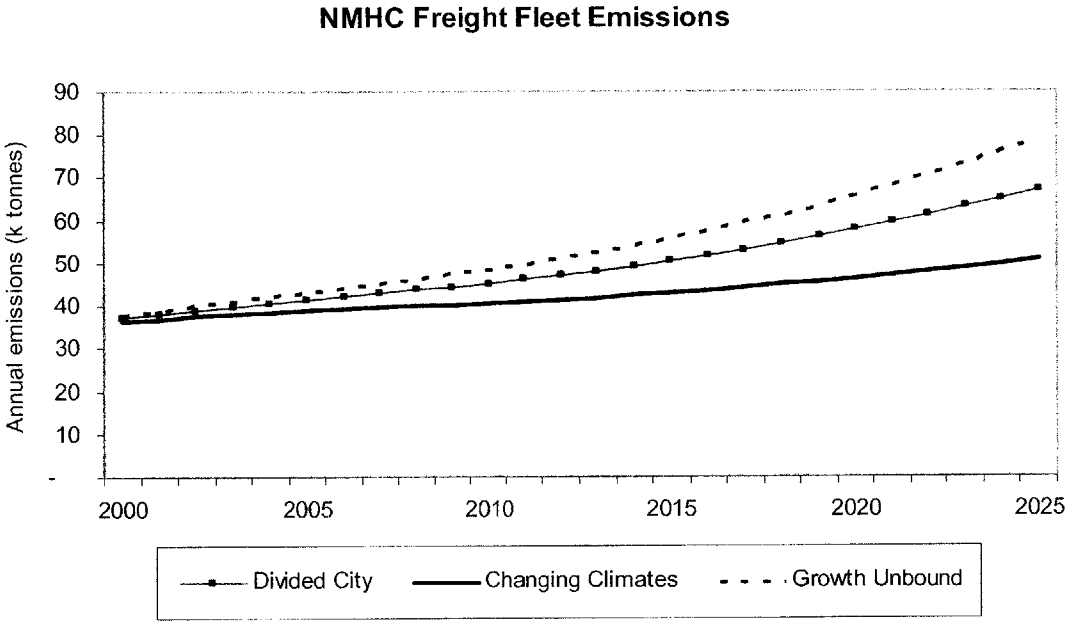


Figure 3-9 shows that NMHC freight-related emissions would continue to grow under all three future stories, reaching levels between 50 and 80 ktonnes in year 2025, depending on the future story.

Figure 3-10 Freight Transportation NOx Pollutant Emissions

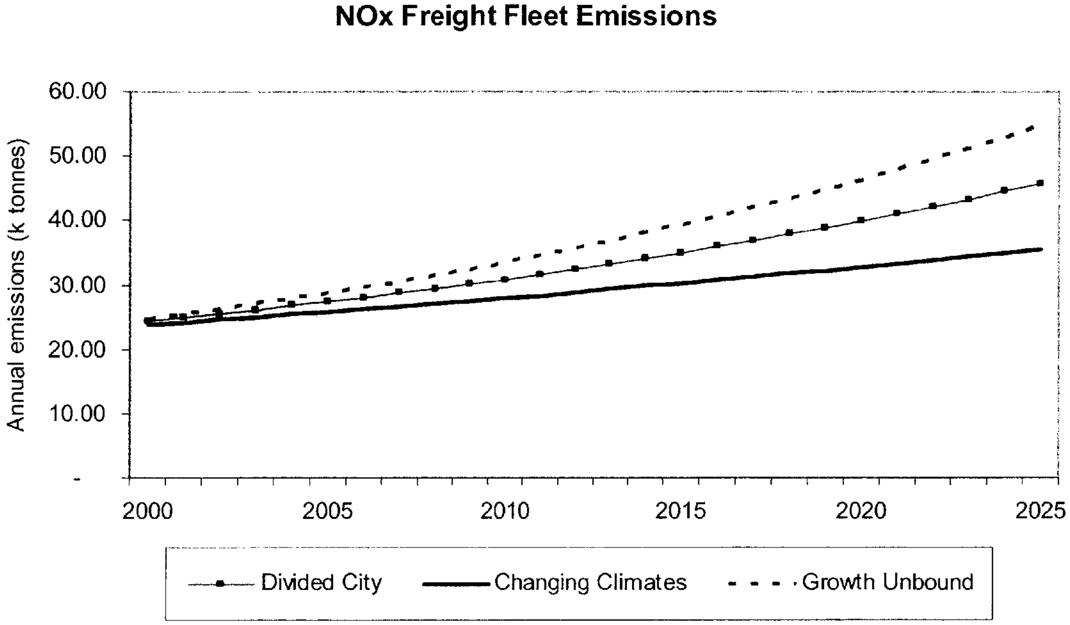


Figure 3-10 shows that NOx freight-related emissions would also continue to grow under all three future stories. Their level in year 2025 would range between 45 and 55 ktonnes depending on the future story.

Figure 3-11 Freight Transportation PM$_{10}$ Pollutant Emissions

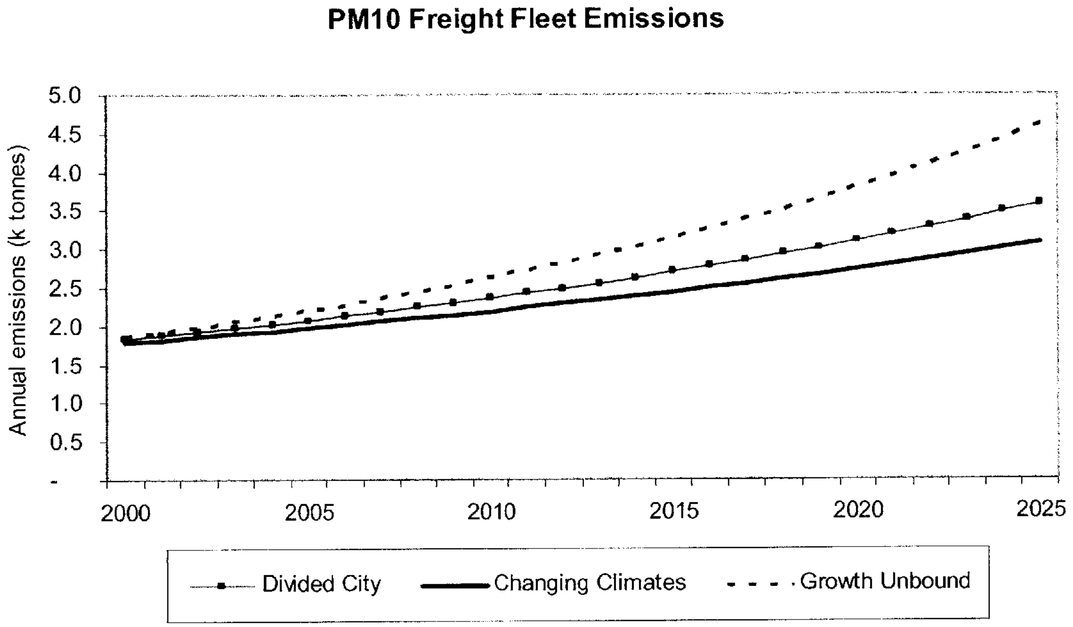
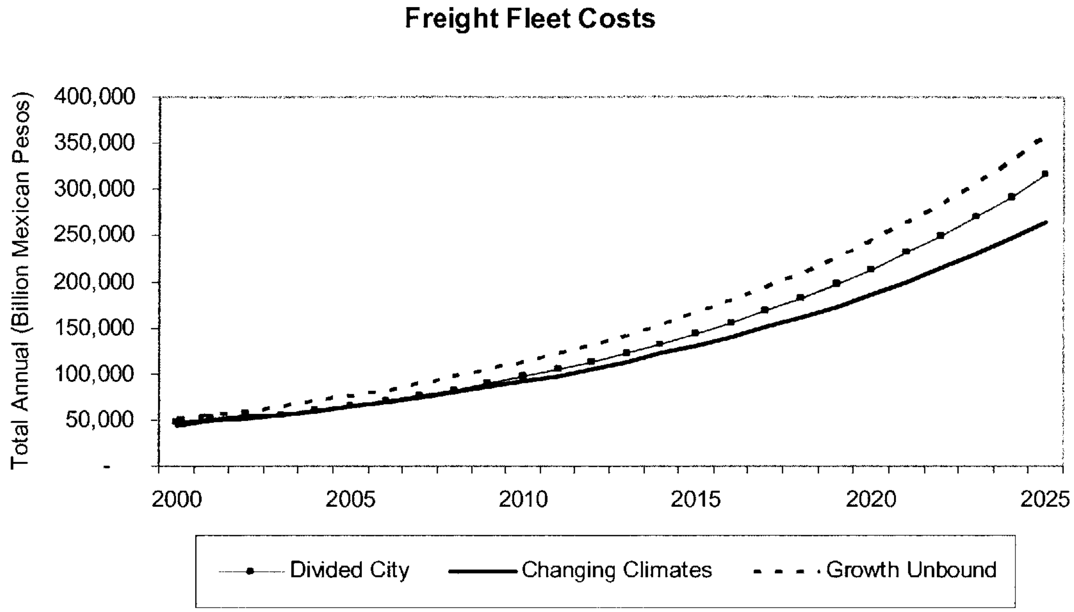


Figure 3-11 shows that similarly to other pollutant emissions analyzed, freight-related PM$_{10}$ emissions would also continue to grow significantly, reaching levels between 2.8 and 4.7 ktonnes in year 2025 depending on the future story.

Figure 3-12 Freight Transportation Total Annual Costs



Notes: 1) Figures are in nominal pesos; 2) Figures do not include railroad costs

Figure 3-12 shows that the costs of the MCMA freight fleet would continually raise in the period analyzed (2000-2025). This growth is due to the growth in freight transportation demand in the MCMA. It is worth recalling that the annual costs presented in figure 3-10 are in nominal pesos.

Finally, the present values of the total annual costs of the MCMA freight fleet are presented in table 3-3. These costs would range between 749 and 1,356 BYBMXP[36] depending on the future story.

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[36] Year 2000 Billion Mexican Pesos

Table 3-3 Present Value of Total Costs of the MCMA Freight Fleet

Emissions/Costs[1/]	**Divided City**	**Changing Climates**	**Growth Unbound**
	Base	Base	Base
Capital Cost (Present Value)	182	255	370
Energy Cost (Present Value)	146	147	278
Other Costs [2/] (Present Value)	421	523	708
Total MCMA Freight Fleet Costs (Present Value)	749	925	1,356

1/ All costs are in billion year 2000 Mexican Pesos

2/ Other costs include: maintenance costs, labor costs, government fees, insurance costs and air quality enforcement costs.

Note: Does not include railroad costs

3. 6 Model Limitations

It is important to notice that all models, including this one, are a simplification of the real world and consequently are subject to errors. As mentioned by Sussman (2000) "all models are wrong, however some are useful". The model presented here can help us understand the evolution of freight transportation demand in the MCMA. Furthermore, we can use it to evaluate freight-related strategies to improve air quality in the MCMA. The results we get from the model will most likely not be exact figures; however, they can help us understand the overall trends, as well as the impact of freight strategies on emissions and costs.

This model only includes freight transportation vehicles; thus when evaluating strategies, their impact on emissions and costs will only be quantified based on these types of vehicles. Therefore, it is possible that their impact is underestimated. For instance, a strategy that improves freight operations in the MCMA will probably have a considerable impact on the level of pollutant emissions from other vehicles (i.e. private autos); however, by using our model we will only quantify the impact on freight vehicles. Furthermore, the impact of strategies concerning congestion on the road network will not be captured fully by this model; however, we can use it to get a first estimate of such impact. If it proves to be substantial, further efforts to create a more detailed model to evaluate that strategy could be developed.

We believe the model is appropriate for the objectives of this thesis and can be improved later on with the availability of better quality and methods. For instance, as mentioned earlier, the freight composition in the MCMA is an exogenous variable; however, it could be possible to make it an endogenous variable by constructing a behavioral model (i.e. multinomial logit or nested logit) by including characteristics of the road network, freight vehicles and freight vehicle owners.

3.7 Key Findings

In this chapter we have developed a model that will help us evaluate freight-related strategies to improve air quality in the MCMA. Using the model, as well as the future stories created, can help us better deal with the uncertainty inherent in planning for a twenty five year horizon. As mentioned earlier, all freight-related strategies should be tested using the model under all three future stories in order to determine their robustness with respect to the uncertainties posed by the key drivers included in the future stories.

The model results indicate that freight transportation demand in the MCMA will continue to grow considerably in the future under all future stories analyzed. The effect of this growth will be a growth in pollutant emissions and costs.

Having introduced the future stories, and developed the freight-emissions-cost model, we can move on to devising and evaluating freight strategies to improve air quality in the MCMA. In the next three chapters, we include a description and evaluation of freight-related strategies that could potentially be implemented in the MCMA.

CHAPTER 4: EVALUATION OF GOVERNMENT STRATEGIES RELATED TO FREIGHT TRANSPORTATION

This chapter describes the strategies proposed by the government to reduce emissions related to freight transportation vehicles. It addresses issues related to uncertainty for each strategy, and analyzes their performance in terms of emissions of key pollutants, as well as the costs of operating the MCMA's freight fleet if they are implemented.

4.1 Government Efforts to Improve Air Quality (PROAIRE)

Over the past few decades air quality in the MCMA has deteriorated considerably. The city has reached extremely high and severe pollutant emission levels which are hindering its development. Thus, air quality has become a first order public policy issue. Government officials, concerned about this, have made significant efforts towards improving air quality. In an effort to address the issue effectively, in 1992 government officials of the Distrito Federal (DF), the Estado de Mexico (EM) and the Federal Government created the Metropolitan Environmental Commission (CAM[37]). As stated in its mission, this Commission is responsible for "defining and coordinating policies, programs, projects and actions related to the protection of the environment, its preservation and restoration of the ecological equilibrium in the Mexico City Metropolitan Area".

Throughout its history, the CAM has devised and published two programs for improving air quality in the MCMA.

1. *Programa para Mejorar la Calidad del Aire en el Valle de México 1995-2000.* This program was published in 1995 and includes strategies aimed towards reducing emission related to industrial establishments and the transportation sector. However, it did not include any clear strategies aimed directly towards freight transportation.

2. *Programa para Mejorar la Calidad del Aire de la Zona Metropolitana del Valle de México 2002-2010 (PROAIRE).* This latest program was published in 1998. It includes the estimation of pollutant emissions from different sources, including freight

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[37] Comisión Ambiental Metropolitana

transportation. Most importantly, it includes strategies aimed towards reducing emissions from the industrial, commercial, informal and transportation sectors. In terms of freight transportation, this program is the first to explicitly include strategies related towards this important sector.

4.2 Description of Freight-related Strategies in the PROAIRE

The PROAIRE includes three strategies that are directly related to freight transportation. These strategies are the following:

1. Introduction and implementation of stricter emission standards for new heavy-duty diesel vehicles.
2. Implementation of a diesel engine retrofit program.
3. Implementation of a heavy-duty gasoline freight vehicle substitution program.

For the analysis of the performance of these strategies, a base case and two versions of these strategies, which have been labeled IDEAL PROAIRE Case and MIT PROAIRE Case, were constructed. The Base Case reflects a "business as usual" situation. It illustrates how emissions would behave in the future if no strategies are implemented during the time horizon analyzed. The IDEAL PROAIRE Case contains the strategies proposed by government officials included in the PROAIRE with their desired compliance levels and deployment schedules. The MIT PROAIRE Case includes the same options, but with compliance levels and deployment schedules considered to be less aggressive and more realistic.

The MIT PROAIRE Case was constructed in part to deal with the uncertainty in the effectiveness of the strategies included in the PROAIRE. The IDEAL PROAIRE Case assumes that government strategies will be implemented perfectly; however, this seems unrealistic. Thus, by introducing the MIT PROAIRE Case we are in fact testing the effectiveness of the strategies if their desired compliance levels or deployment schedules are not met. For example, in the case of the first government strategy, the implementation of stricter emission standards for new heavy-duty diesel vehicles, the IDEAL PROAIRE Case assumes the deployment schedule would be the same as the one proposed in the United States of America; however, this seems unlikely in the

Mexico City Metropolitan Area. Therefore, the deployment schedule in the MIT PROAIRE Case extends the deployment schedule five more years.

By having both the IDEAL PROAIRE Case and MIT PROAIRE Case we can avoid situations in which government strategies that seem to be effective under the IDEAL PROAIRE Case are actually implemented only to find out later on that if their proposed objectives or deployment schedules are not perfectly met they are not as effective. On the other hand, if a strategy is capable of achieving substantial and sustained emissions reductions under both the IDEAL PROAIRE Case and MIT PROAIRE Case, we can more safely guarantee its effectiveness; thus, it can be considered to be more "robust" with respect not only to different future scenarios of the MCMA, but also to distinct compliance levels and deployment schedules.

4.2.1 Government Strategy 1: Introduction and implementation of stricter emission standards for new heavy diesel vehicles

The objective of this strategy is to lower the emission rates of new heavy-duty diesel vehicles for three key pollutants, non-methane hydrocarbons (NMHC), nitrogen oxides (NO_x) and particulate matter (PM_{10}). The PROAIRE establishes that the emission standards would be based on EPA-2004 and EPA-2007 regulations. These regulations have been established in the United States in an effort to reduce emission levels for these three pollutants attributable to heavy-duty diesel vehicles.

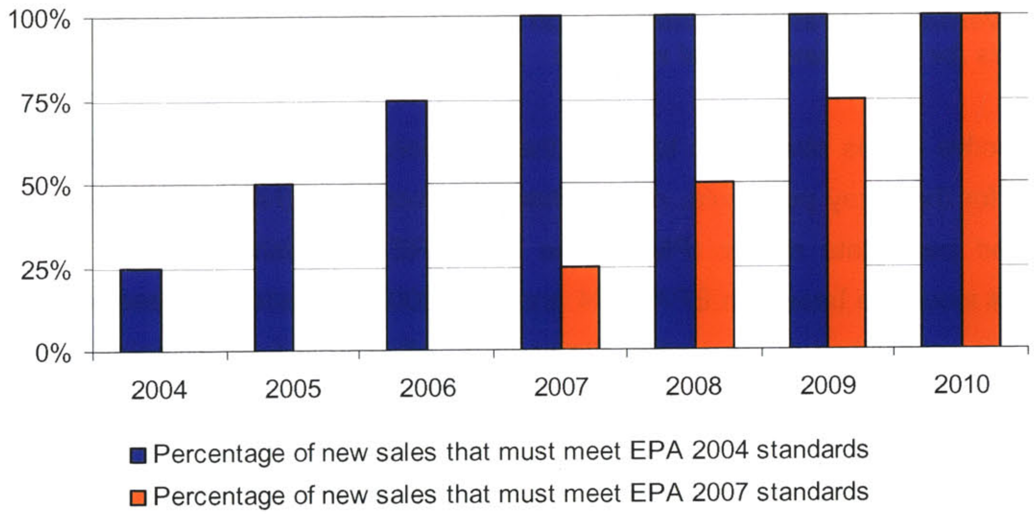
The deployment schedule and emission standards for the IDEAL PROAIRE Case were assumed to be the same as the ones included in EPA-2004 and EPA-2007 regulations. The MIT PROAIRE Case is also based on EPA regulations; however, it differs from the IDEAL PROAIRE in its deployment schedule. Historically, there has been a time lag between the United States and Mexico with respect to vehicle emissions technology. Emissions and fuel efficiency technology is introduced first in the United States and some years later in Mexico.

In order to meet EPA-2004 and EPA-2007 regulations, new heavy-duty diesel vehicles will have to be equipped with more advanced technology than they currently have. These technological improvements are planned to be included in new heavy-duty diesel vehicles in the United States in time to meet both EPA-2004 and EPA-2007 regulations;

however, assuming that such technological improvements will be available and included in new heavy-duty diesel vehicles in Mexico at the same time as in the United States seems unrealistic. The MIT PROAIRE Case incorporates this information by assuming a different and less aggressive deployment schedule than the IDEAL PROAIRE Case.

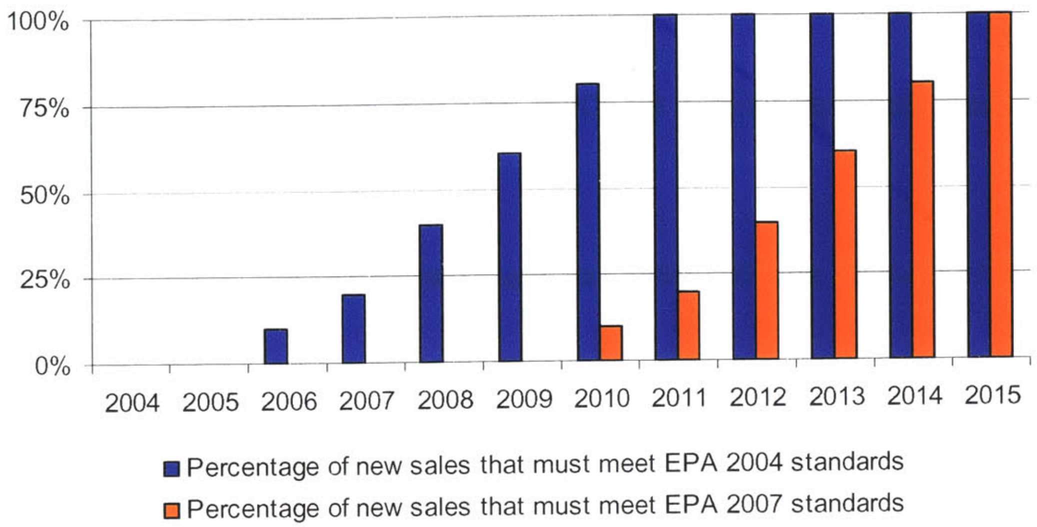
Figure 4-1 and 4-2 include the deployment schedules for both the IDEAL PROAIRE and MIT PROAIRE Cases.

Figure 4-1 Government Strategy 1. Deployment Schedule for the IDEAL PROAIRE Case



The IDEAL PROAIRE Case establishes that in a four year period (2004-2007) all new heavy-duty diesel vehicles would be required to meet EPA-2004 emission standards. The deployment schedule would be phased in incrementally, starting with only 25% of all new vehicle sales in 2004, 50% in 2005, 75% in 2006 and finally 100% in 2007. In this last year, 25% of all new heavy-duty vehicle sales would also have to comply with EPA-2007 emission standards. Again, the deployment schedule would be phased in at 25% yearly increments up to the year 2010 when all vehicles would be required to meet these standards. Therefore, the total length of this strategy for the IDEAL PROAIRE Case would be seven years, from 2004 to 2010.

Figure 4-2 Government Strategy 1. Deployment Schedule for the MIT PROAIRE Case



The MIT PROAIRE Case assumes that the same emission standards would have to be complied with; however, as stated earlier, the deployment schedules would be less aggressive. For example, its deployment schedule would start two years later than in the IDEAL PROAIRE Case. All new heavy-duty diesel vehicles would have to comply with EPA-2004 emission standards in a period of six years (2006-2011) instead of four years. The phase-in schedule would also be incremental, 10% in the first year and 20% increments for each subsequent year, reaching 100% in 2011. The deployment schedule for the compliance of EPA-2007 emission standards would last six years (2010-2015) as well. The phase-in schedule would also be 10% in the first year and 20% increments for each subsequent year, reaching 100% in 2015. The total length of this strategy for the MIT PROAIRE Case would be 12 years (2004-2015).

The emission standards for both the IDEAL and MIT PROAIRE Cases were assumed to be the same as EPA-2004 and EPA-2007 standards.

The reasoning behind this assumption is based upon the fact that in the near future freight vehicles from Mexico will be allowed to circulate on American highways and vice versa[38]. These vehicles will only be able to use American highways if they are in compliance with current United States' regulations. Since heavy-duty diesel vehicles are mostly used for long-haul trips, it seems reasonable to assume that in the future new heavy-duty truck models will have the technology needed to comply with United States' air quality standards.

The emission standards for both the IDEAL and MIT PROAIRE Cases are shown in table 4-1.

Table 4-1 EPA-2004 and EPA-2007 Emission Standards

Emission Standards	**NOx+NMHC (g/bhp-hr)**	**PM_{10} (g/bhp-hr)**
EPA-2004	2.4	0.1
EPA-2007	0.2	0.01

4.2.2 Government Strategy 2: Implementation of a diesel engine retrofit program.

The objective of this strategy is lowering emission rates for the local heavy-duty diesel vehicles that are currently circulating on Mexico City's road network. This strategy is aimed towards four types of pollutants, non-methane hydrocarbons (NMHC), carbon monoxide (CO), nitrogen oxides (NO_x) and particulate matter (PM_{10}).

The PROAIRE does not include an explicit description of the technologies that will be used to for retrofitting the diesel engines. Therefore, it was assumed that currently available retrofit technologies would be installed. Two different retrofit technologies were considered:

1. Diesel Oxidization Catalysts. These devices are typically composed of a stainless steel canister installed in the exhaust system. The canister contains a honeycomb-shaped substrate coated with catalytic metals such as platinum or palladium. The canister does not have moving parts. As exhaust gases pass through the honeycomb structure, pollutants and particulate matter are chemically oxidized to water vapor and carbon dioxide. These retrofit devices are

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[38] This information is based on the North American Free Trade Agreement (NAFTA).

attractive for two main reasons: 1) they can be used with existing diesel fuel, and 2) they offer respectable emission rate reductions and do not require engine modifications for their installment. Therefore, they can be installed in most heavy-duty diesel vehicles currently using the road network, including old model year vehicles (1980 and older).

2. Diesel Particulate Filters. These devices filter and physically trap particles in the engine exhaust before it leaves the tailpipe. The filters are made of corderite, silicon carbide or some other material. Removing particulate matter trapped in the filter is called regeneration because it restores filter efficiencies. The effectiveness of these devices is considerably higher than diesel oxidization catalysts; however, in order to operate properly and effectively, they require the use of low sulphur diesel, 30 ppm on average. These retrofit devices would be used only on relatively new vehicles, model year 1995 and newer. The effectiveness of these devices is considerably higher than CEM filters.

The retrofit devices and their effectiveness, assumed for both the IDEAL PROAIRE Case and MIT PROAIRE Case are shown in table 4-2.

Table 4-2 Retrofit Devices for Diesel Engines

Retrofitting Technology	Retrofit Device	Manufacturer	Percentage Reduction (%)		
			PM_{10}	NOx	NMHC
Diesel Oxidization Catalysts	Catalytic Exhaust Mufflers (CEM II)	Johnson Matthey	33%	4%	50%
Diesel Particulate Filters	Continuously Regenerating Technology (CRT)	Johnson Matthey	60%	8%	60%

Source: www.jmcsd.com

The PROAIRE states that all local heavy-duty diesel vehicles, model year 1990 and previous would be retrofitted in the years 2005-2010. This implies that 34,000 heavy-duty diesel vehicles would be retrofitted in six years, approximately 5,700 per year. The IDEAL PROAIRE Case assumes that this number of vehicles would be retrofitted in the same time period.

The MIT PROAIRE Case for this strategy differs with the IDEAL PROAIRE Case in two aspects. First, some retrofit devices, specifically diesel particulate filters, require the availability of low sulphur diesel[39]. All diesel fuel-related decisions in Mexico are made by the state-owned company Petróleos Mexicanos (PEMEX). PEMEX officials have said that they do not intend to make low sulphur diesel available in Mexico before the year 2007[40]. Therefore, the MIT PROAIRE Case assumes that the diesel engine retrofit program would begin in 2007.

Second, considering this would be the first time a strategy to retrofit heavy-duty diesel engines is implemented in the MCMA, it is quite possible that all vehicles originally planned to be retrofitted will not be retrofitted simply because vehicle owners will not do it. This is certainly possible if we further consider that the MCMA has historically been characterized by its laxness in implementing vehicle regulations.

Having this in mind, the MIT PROAIRE Case assumes that a lower number of heavy-duty diesel vehicles would actually be retrofitted. More specifically, it assumes that all heavy-duty diesel vehicles model year 1980 and previous would be retrofitted. This

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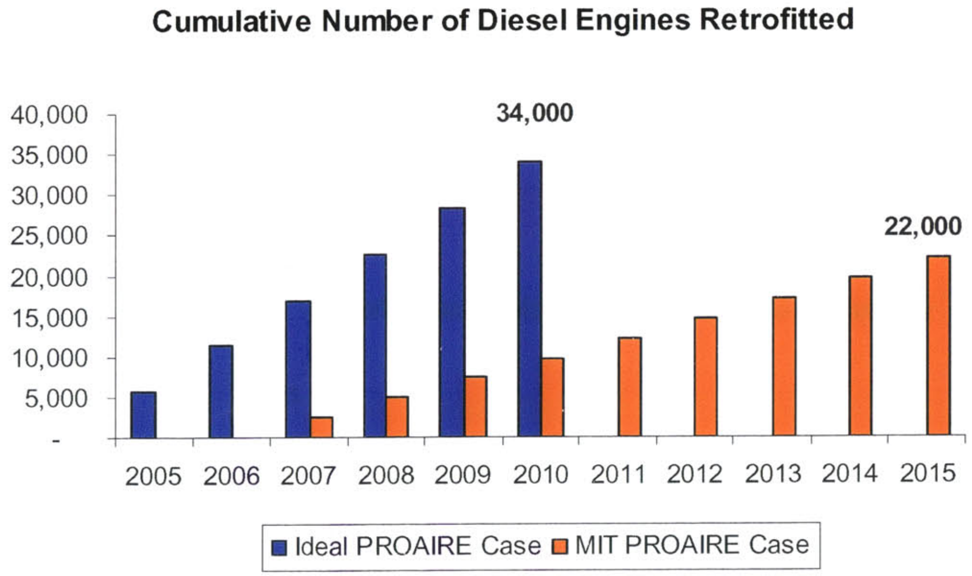
[39] Diesel with sulphur levels less than 50 ppm.

[40] Group Research Meeting with PEMEX Officials on July 2002.

reduces the number of vehicles retrofitted, but keeps the older vehicles, which emit the most pollutants, in the program. Furthermore, it assumes that the deployment schedule would go until 2015, thus implying that 22,000 heavy-duty diesel vehicles (65% of the vehicles included in the IDEAL PROAIRE) would be retrofitted in a ten year period, approximately 2,200 vehicles per year.

The deployment schedules for both the IDEAL PROAIRE Case and the MIT PROAIRE Case are shown in figure 4-3.

Figure 4-3 Government Strategy 2. Deployment Schedule for the IDEAL PROAIRE Case and the MIT PROAIRE Case



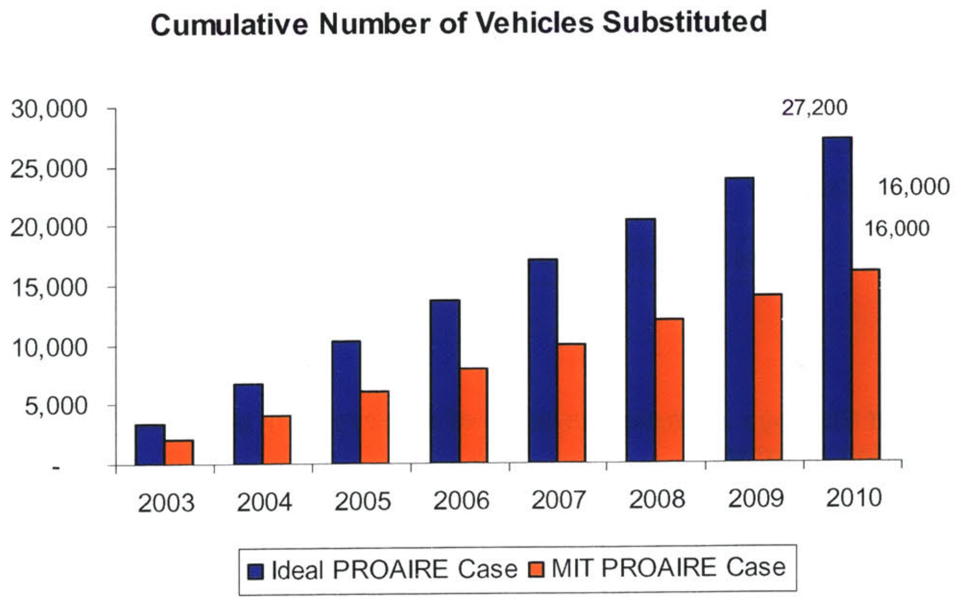
4.2.3 Government Strategy 3. Implementation of a heavy-duty gasoline freight vehicle substitution program

The objective of this strategy is to renew the current heavy gasoline vehicle fleet by replacing obsolete vehicles with new ones. The strategy is aimed towards reducing mainly non-methane hydrocarbons (NMHC) and carbon monoxide (CO).

The PROAIRE states that 3,400 heavy-duty gasoline vehicles would be substituted each year from 2003 to 2010 amounting to approximately 27,000 heavy-duty gasoline vehicles substituted in an eight year period. The IDEAL PROAIRE Case assumes that the same number of vehicles would be substituted in the same time period.

This strategy if implemented would represent the first attempt to renew the freight vehicle fleet by substituting older vehicles with new ones. Following a similar argument than the one presented in the second government strategy (diesel engine retrofit program), it is possible that the planned number of vehicles to be substituted in the IDEAL PROAIRE might not be met. Therefore, the MIT PROAIRE Case assumes that only 2,000 heavy-duty gasoline vehicles would be substituted each year in an eight year period, amounting to approximately 16,000 heavy-duty gasoline vehicles substituted (60% of the total number of vehicles included in the IDEAL PROAIRE). Figure 4-4 illustrates the deployment schedule for both the IDEAL PROAIRE Case and the MIT PROAIRE Case.

Figure 4-4 Government Strategy 3 Deployment Schedule for the IDEAL PROAIRE Case and the MIT PROAIRE Case



4.2.4 Summary of Freight-related Strategies in the PROAIRE

Summarizing, there are three government strategies related to freight transportation in the PROAIRE. These strategies are aimed towards reducing emissions from two different components of the freight fleet in the MCMA, the heavy-duty diesel and the heavy gasoline vehicle fleets. Table 4-3 illustrates these strategies, their objectives, as well as their deployment schedules under the IDEAL PROAIRE Case and the MIT PROAIRE Case.

Table 4-3: Summary of the Government Strategies for the IDEAL PROAIRE Case and the MIT PROAIRE Case

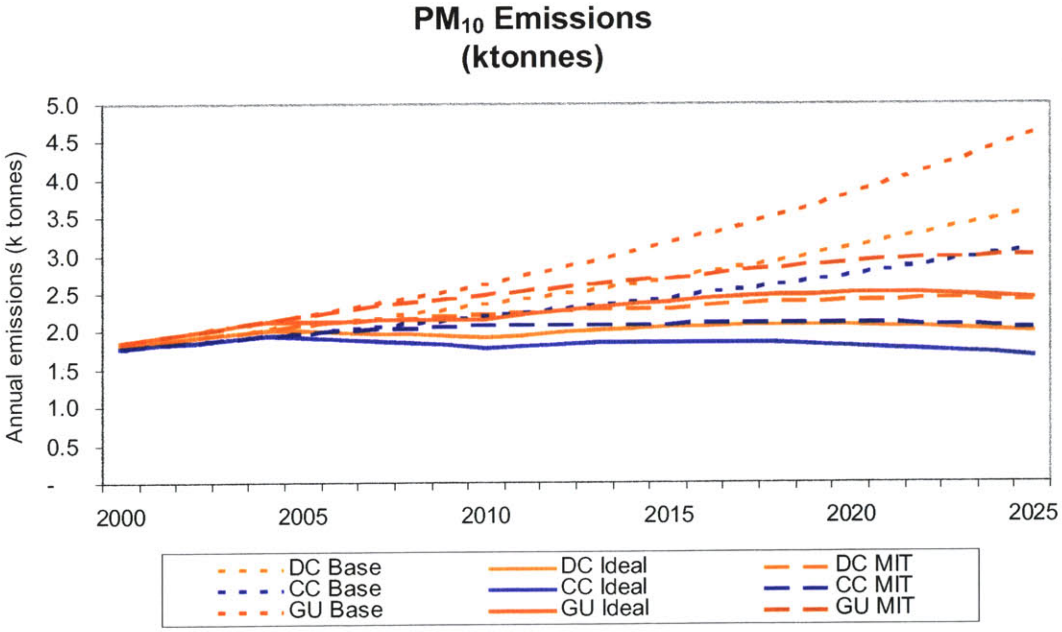
Strategy	**Objective**	**IDEAL PROAIRE**		**MIT PROAIRE**	
		Deployment Schedule	**Total number of vehicles in program**	**Deployment Schedule**	**Total number of vehicles in program**
Stricter Emission Standards for New Heavy Diesel Vehicles	Introduction of new diesel vehicles with lower levels of pollutant emissions, especially NOx and PM_{10}.	Starts 2004 Ends 2010	N/A	Starts 2006 Ends 2015	N/A
Diesel Engine Retrofit Program	Reduction of emissions by introducing emission control systems for PM_{10} and NOx.	Starts 2005 Ends 2010	34,000	Starts 2007 Ends 2015	22,000
Gasoline Freight Vehicle Substitution	Substitution of obsolete local gasoline powered trucks with new gasoline powered trucks.	Starts 2003 Ends 2010	27,000	Starts 2003 Ends 2010	16,000

4.3 Emissions and Costs of PROAIRE Measures

Having specified all three government strategies, we can now test their effectiveness in terms of emissions reductions and costs by using the Emissions and Costs Models described in Chapter 3.

A thorough analysis shows that the government strategies included in the PROAIRE would not be able to achieve substantial and sustained emissions reductions for key pollutants over the long term for the Base, IDEAL and MIT PROAIRE Cases under any of the three future stories, as illustrated in figures 4-5, 4-6, 4-7 and 4-8.

Figure 4-5 PM_{10} Emissions for the Base, IDEAL PROAIRE and MIT PROAIRE Cases for all three Future Stories

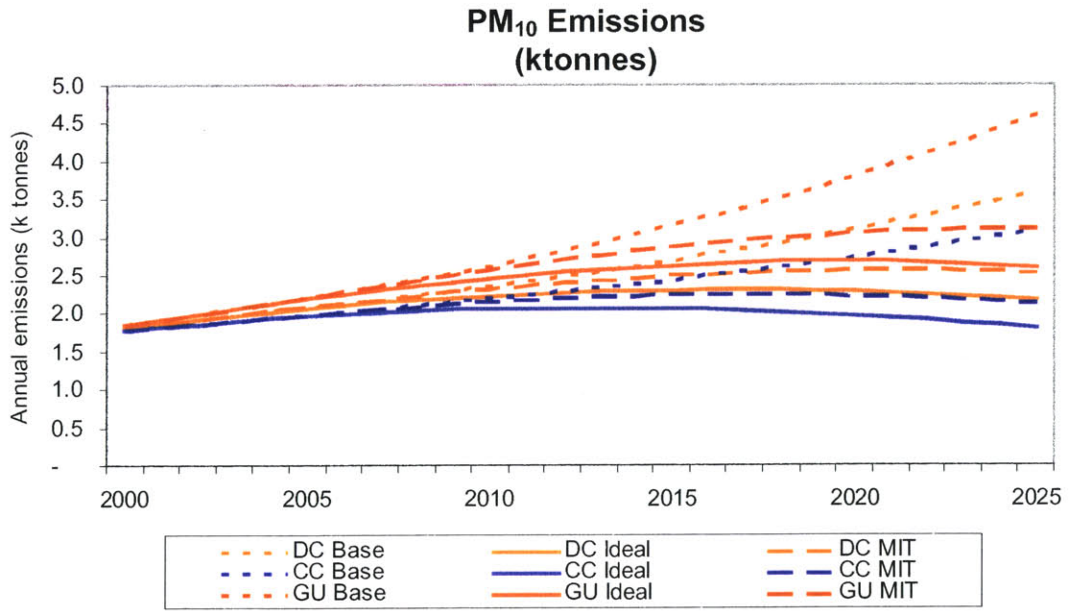


Note: DC = "Divided City"; CC = "Changing Climates"; GU = "Growth Unbound"
Emissions estimates based on the emissions model presented in Chapter 3.

From figure 4-5 we can take two different readings. The first is that PM_{10} emissions would not be reduced substantially if the IDEAL PROAIRE or MIT PROAIRE Cases are implemented. Secondly, PM_{10} emissions would stabilize approximately by the year 2020 if either the IDEAL PROAIRE or MIT PROAIRE Cases are implemented. In fact, under the future story "Changing Climates" PM_{10} emissions would stabilize approximately in the year 2018 and decrease to similar emission levels as in the year 2000. This stabilization is attributable to the first government strategy which calls for stricter PM_{10} emissions standards. If this strategy is implemented, future model vehicles will produce significantly lower unit emissions, measured as grams/mile, than current vehicles. Under this strategy, even when the freight vehicle fleet remains old in the future (older than 15 years), the unit emissions of old vehicles would be considerable lower than that of current vehicles. For example, a 1990 model truck would have emitted much higher PM_{10} emissions in the year 2000 than those of a 2010 model truck in the year 2020.

Through the estimation of the amount of PM_{10} emissions reductions attributable solely to the first government strategy (stricter emission standards) we can confirm the fact that this strategy is responsible for the stabilization of PM_{10} emissions levels, as shown in figure 4-6.

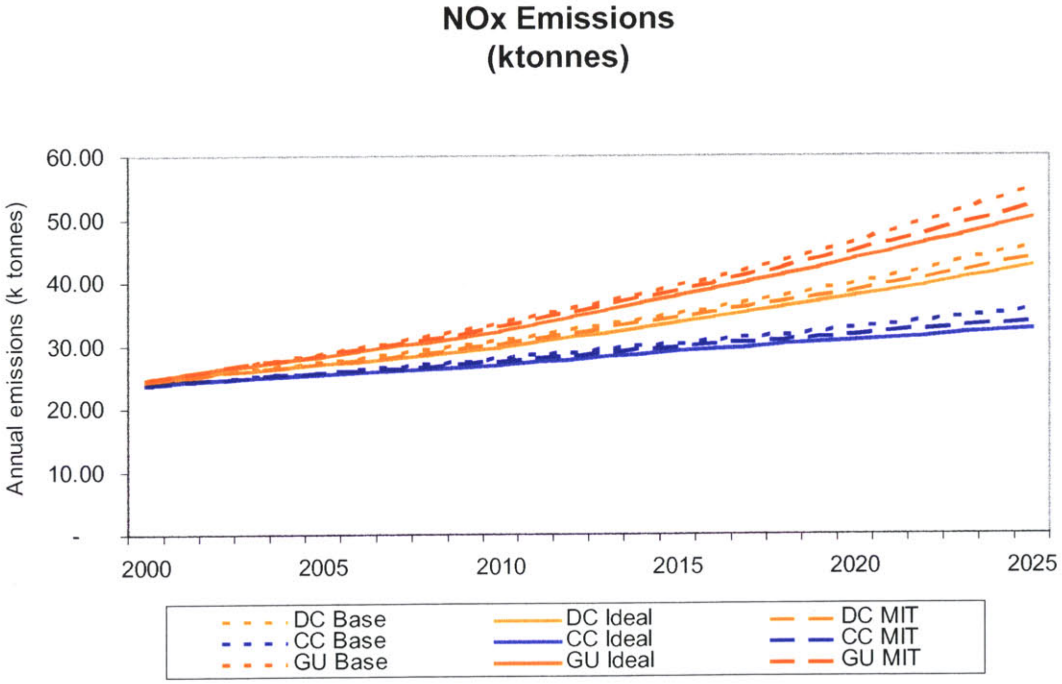
Figure 4-6 PM_{10} Emissions for the First Government Strategy (Stricter emission standards) for all three Future Stories



By comparing figures 4-5 and 4-6 we can see that PM_{10} emission' reductions under the IDEAL and MIT PROAIRE cases can be mostly attributable to the stricter emission standards strategy. In fact, the diesel engine retrofit and the gasoline vehicle substitution strategies will only have an effect in emission levels throughout a short period of time, approximately from 2005-2015. Therefore, their effectiveness for achieving sustained emissions reductions for this particular pollutant is considerably limited.

As far as NO_x emissions, from figure 4-7 we can note that they would continue to increase significantly under the Base, IDEAL PROAIRE and MIT PROAIRE cases under all three future stories. Both the IDEAL and MIT PROAIRE cases would slightly decrease the rate of growth of emissions; however, freight transportation demand in the MCMA would overwhelm any emissions reductions obtained by implementing either one of them.

Figure 4-7 NO_x Emissions for the Base, IDEAL PROAIRE and MIT PROAIRE Cases for all three Future Stories

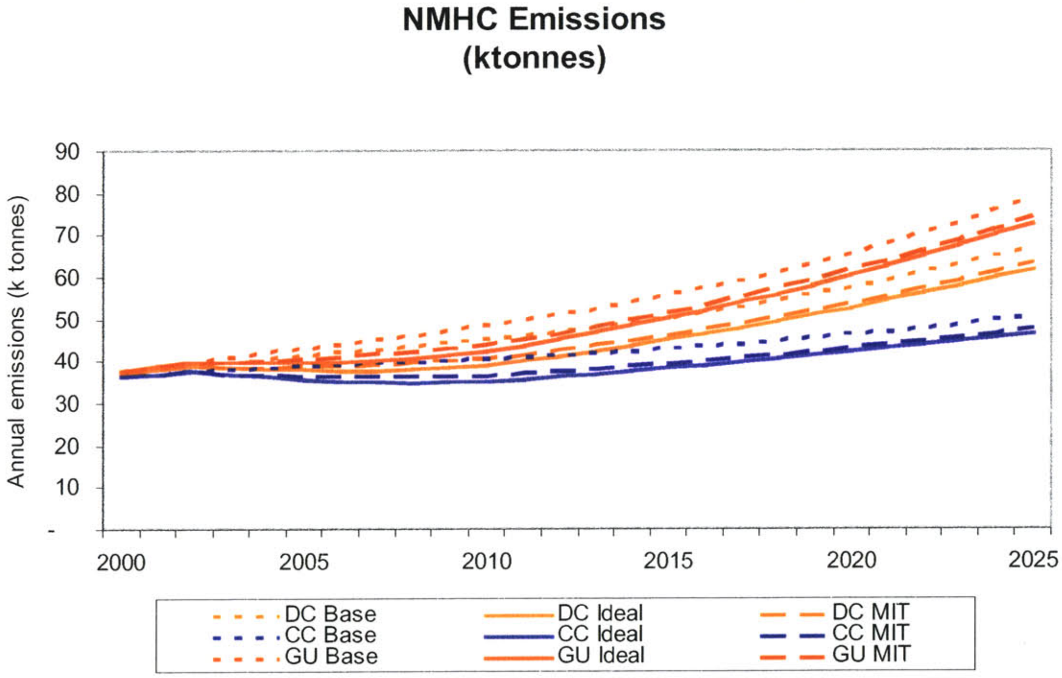


Note: DC = "Divided City"; CC = "Changing Climates"; GU = "Growth Unbound"
Emissions estimates based on the emissions model presented in Chapter 3.

As seen in figure 4-8 NMHC emissions would also continue to grow under the Base, IDEAL PROAIRE and MIT PROAIRE cases for all three future stories. In fact, the IDEAL PROAIRE and MIT PROAIRE cases would only reduce NMHC emissions in the period

2003-2010, which corresponds to the deployment schedule of the government's third strategy (substitution of heavy-duty gasoline vehicles); however, these emissions reductions would not be sustained because of the increase in the number of freight vehicles using the road network in the MCMA caused by the increase in freight transportation demand.

Figure 4-8 NMHC Emissions for the Base, IDEAL PROAIRE and MIT PROAIRE Cases for all three Future Stories



Figures 4-5, 4-6, 4-7 and 4-8 show the trajectory of emissions for the Base, IDEAL PROAIRE and MIT PROAIRE cases. These trajectories include the effect of all three government strategies included in both the IDEAL PROAIRE and the MIT PROAIRE cases. However, it is useful to not only test all three strategies' effectiveness in achieving emissions reductions collectively, but also individually.

Table 4-4 shows emissions levels for the year 2025 if each government strategy was implemented solely without including the other two strategies. The table also includes emissions levels for both the base case and the IDEAL PROAIRE in order to assess their contribution to the overall effectiveness of the portfolio of government strategies.

Table 4-4 Emission Levels in the Year 2025 for Key Pollutants under each Government Strategy

	PM_{10}			NO_X			NMHC		
	DC	**CC**	**GU**	**DC**	**CC**	**GU**	**DC**	**CC**	**GU**
Base Case	3.6	3.1	4.6	46	35	55	67	51	79
Stricter Emission Standards	2.2	1.8	2.6	42	33	50	64	48	75
Diesel Engine Retrofit Program	3.4	2.9	4.4	45	34	54	66	50	78
Heavy Gasoline Truck Substitution	3.6	3.1	4.6	45	35	55	65	49	77
IDEAL PROAIRE	**2.0**	**1.7**	**2.4**	**41**	**32**	**50**	**62**	**46**	**73**

Note: DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound".
All figures are ktonnes.

From table 4-4 we can take three readings. The first is that practically all PM_{10} emissions reductions can be attributable to the first government strategy (stricter emission standards). If either of the other two strategies was implemented by itself, PM_{10} emission levels in the year 2025 would be practically the same as in the base case. Second, if any of the three government strategies was implemented by itself, NO_X and NMHC emissions would practically be the same as in the base case. Third, of all three strategies, the only one that contributes significantly to emissions reductions is the first strategy (stricter emission standards); however, its contribution is limited to PM_{10} emissions.

The reason why the diesel engine retrofit and the heavy gasoline truck substitution strategies would have such a small impact on emissions reductions can be traced back to the way those strategies were set up. The diesel engine retrofit strategy is aimed towards retrofitting the current local heavy-duty diesel fleet. In doing so, it fails to consider two issues that seriously undermine its performance. First, even when a considerably number of heavy-duty diesel trucks would be retrofitted, the strategy does not include any restriction to keep old heavy-duty diesel vehicles from other regions of the country from entering the freight vehicle fleet in future years. Secondly, the retrofit devices that can be installed in old heavy-duty diesel trucks do not provide sufficient emissions reductions to cause an impact in the total level of emissions. In fact, the main attractiveness of these devices is not the amount of emissions reduction they can provide, but rather that they can easily be installed in old heavy-duty diesel trucks. The main setback of the heavy gasoline truck substitution strategy is that it also fails to include some kind of restriction to keep old gasoline trucks from other regions of the country from entering the freight fleet in the MCMA.

We have seen that if no government strategies are implemented (Base Case), NOx and PM_{10} and NHMC emissions would be significantly higher by the year 2025, compared to 2000. However, if either these strategies are implemented the costs of the MCMA's freight fleet would also rise significantly. For example, these costs would rise from 749 BYMXP[41] to 758 or 760 BYMXP for the future story "Divided City", as shown in table 4-4.

Table 4-5 Costs of Government Strategies for all Three Future Stories

Emissions/Costs[1/]	**Divided City**			**Changing Climates**			**Growth Unbound**		
	Base	IDEAL	MIT	Base	IDEAL	MIT	Base	IDEAL	MIT
Capital Cost (Present Value)	182	189	188	255	264	261	370	380	378
Energy Cost (Present Value)	146	145	146	147	145	145	278	277	277
Other Costs [2/] (Present Value)	421	426	424	523	528	528	708	713	712
Total MCMA Freight Fleet Costs (Present Value)	749	760	758	925	937	934	1,356	1,370	1,367
	PV 2000-2025, r=13%			PV 2000-2025,r=10%			PV 2000-2025, r=8%		

1/ All costs are in billion year 2000 Mexican Pesos
2/ Other costs include: maintenance costs, labor costs, government fees, insurance costs and air quality enforcement costs.

4.4 Key Findings and Assessments

The three government strategies related to freight transportation included in the PROAIRE if implemented could achieve modest emissions reductions for key pollutants.

If either the IDEAL PROAIRE or the MIT PROAIRE cases are implemented future PM_{10} emission levels would stabilize approximately by the year 2020. However, for NOx and

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[41] BYMXP= billion year 2000 Mexican Pesos

NHMC, emissions would continue to grow under any of the cases (Base, IDEAL PROAIRE and MIT POAIRE) and future stories analyzed. For these two key pollutants any emissions reductions achieved by the IDEAL PROAIRE or MIT PROAIRE cases would be overwhelmed by the increase in the number of freight vehicles that would be using the road network in the future. This increase in the number of freight vehicles would be the result of the continuous growth of freight demand in the MCMA.

The main uncertainty in the evaluation of these options is with respect to the desired compliance levels and deployment schedules assumed by the government. However, this uncertainty is addressed through the construction of the IDEAL PROAIRE and MIT PROAIRE Cases.

Our analysis shows that accounting for this uncertainty we can conclude that even under the most optimistic circumstances analyzed (the IDEAL PROAIRE) and for different scenarios these government strategies would not be sufficient to achieve substantial and sustained emissions reductions for key pollutants, PM_{10}, NOx and NHMC.

Finally, in order to achieve substantial and sustained emissions reductions, it will be necessary to devise strategies that are more aggressive in terms of number of vehicles included, proposed objectives and deployment schedules than the ones included in the PROAIRE. For example, a fleet renewal program, such as the third government strategy should aim at substituting a greater amount of vehicles and dedicate the necessary amount of resources and human capital to ensure that it is implemented as planned.

Substantial and sustained emissions reductions might also be achieved by considering a different approach than that of these government strategies. All three government strategies attempt to achieve substantial and sustained emissions reductions through the use of newer and cleaner technologies; however, it could also be possible to achieve emissions reductions by improvement the daily operations of the freight fleet within the MCMA.

CHAPTER 5: FREIGHT VEHICLE TECHNOLOGY AND FUEL QUALITY IMPROVEMENT STRATEGIES TO IMPROVE AIR QUALITY IN THE MEXICO CITY METROPOLITAN AREA

5.1 Introduction

This chapter describes a series of freight-related strategies that could be applied in the MCMA. It also includes the evaluation of these strategies in terms of their capability of achieving substantial and sustained emissions reductions for key pollutants, particulate matter (PM_{10}), nitrogen oxides (NO_x) and non-methane hydrocarbons (NMHC), as well as the cost of operating the MCMA freight fleet if they are implemented.

Their robustness with respect to the uncertainty posed by the "Future Stories" is analyzed. Another level of uncertainty, present by the fact that strategies might suffer changes in their implementation is also addressed. Each strategy's performance with respect to changes in its objectives, deployment schedule and compliance level has been analyzed and estimated.

Finally, a portfolio of potential strategies to be implemented in the MCMA is presented. The strategies included in the portfolio should be discussed thoroughly with decision makers to assess their political and economical feasibility.

5.2 Types of Freight Strategies

There are different freight-related strategies that can be used to improve air quality in an urban area, such as the MCMA. Based on their characteristics, these strategies can be divided into two categories: 1) freight-related strategies based on vehicle technology and fuel quality improvements; and 2) freight-related strategies based on fleet operational and utilization improvements. In this chapter we will present and discuss strategies included in the first category, while the strategies in the second category will be discussed in Chapter Six.

5.3 Vehicle Technology and Fuel Quality Improvement Strategies

The distinct characteristic of these strategies is that if implemented emissions reductions would be achieved based primarily on the improvement of vehicle technology and fuel quality. Emissions reductions for these strategies would be attributable to lower emission rates for key pollutants.

There are five main vehicle technology and fuel improvement mechanisms, which can be employed to achieve emissions reductions:

1. *Vehicle Fleet Renewal*. The vehicle fleet in any urban area has a renewal rate. Vehicles entering the fleet will remain in it for a time period and eventually leave the fleet for different reasons; for example, vehicles might be sold and taken to a region outside the MCMA, they might be involved in an accident that causes them enough damage to be considered unusable, or companies might decide to replace their old vehicles with newer ones. The behavior of the natural renewal rate depends on the characteristics of the region analyzed. For instance, the fleet renewal rate of urban areas in developing countries is generally lower than that of urban areas in developed countries, which can be explained in part due to the difference in overall economic wealth (personal and corporate income); consequently, the vehicle fleet in developing countries is generally older than in developed countries. There are different policies that if implemented can increase the vehicle fleet renewal rate in an urban setting. For instance, we could establish a maximum vehicle age, or replace used vehicles with newer ones. Increasing the vehicle fleet renewal rate allows us to take advantage of newer and cleaner vehicle technologies, which is particularly important for freight vehicles. For example, a 20 year old light-duty freight gasoline vehicle's NO_x emissions rate is five times higher than that of a new one[42]; thus, by replacing the 20 year old light-duty gasoline vehicle with a new one, we could get an 80% reduction in NO_x emissions attributable to that particular vehicle[43].

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[42] See table 2-6 in Chapter 2.

[43] We would get that reduction if the new light-duty gasoline vehicle is used with the same intensity as the old one.

2. *Vehicle Engine Retrofits*. Vehicle engine retrofits allow us to decrease a vehicle's emission rates without having to modify the vehicle dramatically. A major advantage of retrofitting vehicles is that emissions reductions can be obtained by installing retrofit devices, such as diesel oxidization catalysts or diesel particulate filters, on vehicles currently using the road network of an urban setting without having to replace them. This becomes relevant when considering the costs of either replacing or retrofitting vehicles. In general, retrofitting a vehicle is considerably less costly than replacing it; however, this might not be the case for all types of vehicles. For instance, the cost of replacing an old heavy-duty diesel vehicle might be lower than retrofitting it when considering other costs such as maintenance and fuel consumption. The cost advantage of vehicle engine retrofits with respect to replacing vehicles cannot be extended to emissions reductions. In general, replacing a vehicle will produce greater emissions reductions than retrofitting it. This is particularly true in the case of old vehicles. For example, by retrofitting a 20 year old heavy-duty diesel vehicle we could achieve a 4%[44] reduction in NO_x emission rates, while if we replace it the reduction could amount up to 41%[45].

3. *Stricter Government Standards*. The government can have a considerable influence in the evolution of the vehicle technology by enforcing regulations that ensure that vehicle manufacturers use cleaner technologies. For example, the Environmental Protection Agency (EPA) in the United States has established new regulations for new heavy-duty diesel vehicles which state that new vehicles, starting in 2004, must have the technological requirements to allow them to emit 90% less emissions of particulate matter (PM_{10}).

4. *Fuel Quality Improvements*. Many vehicle technology improvements require the availability of fuel with higher quality standards than currently available. For example, the most effective diesel retrofit devices can only operate properly if the vehicle uses low sulphur fuel[46]. Furthermore, the quality of the fuel will directly influence the characteristics of pollutants emitted by vehicles.

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[44] See table 4-2 in Chapter 4.

[45] See table 2-6 in Chapter 2.

[46] Less than 50 ppm.

For instance, gasoline or diesel with high contents of sulphur will cause vehicles to emit considerable amounts of sulphur oxides, such as SO_2.

5. *Vehicle Conversion or Replacement Based on Fuel Usage*. This mechanism is related to the conversion or replacement of vehicles using a certain type of fuel to using a different type of fuel. For example, a gasoline powered vehicle can be converted to a natural gas powered vehicle or replaced for a natural gas powered vehicle. The benefit in terms of emissions reductions is attributable to the fact that a gasoline powered vehicle has higher emission rates for certain pollutants than a natural gas powered vehicle. For example, PM_{10} emissions rate for a light-duty gasoline vehicle is more than double than that of a light-duty natural gas vehicle[47].

By looking back at the freight-related strategies included in the PROAIRE, we can see that all three of them can be categorized as Vehicle Technology and Fuel Quality Improvement Strategies. In fact, the first government strategy (stricter emissions standards for new heavy-duty diesel vehicles) would be using the third mechanism (stricter government standards) described above; the second government strategy (diesel engine retrofit program) would be using the second and fourth mechanisms (vehicle engine retrofits and fuel quality improvements); and the third government strategy (gasoline freight vehicle replacement program) would be using the first mechanism (vehicle fleet renewal).

The five mechanisms presented above can be used individually or collectively on different freight vehicle fleet components to construct freight-related strategies in the MCMA. For example, a strategy using only one mechanism could be defined as retrofitting the diesel vehicle fleet, while a strategy combining two mechanisms could include retrofitting the diesel vehicle fleet and renewing the gasoline freight fleet. Furthermore, several mechanisms could be used on the same freight fleet component. For example, a strategy could include the retrofitting of 30% of the heavy-duty diesel vehicle fleet and replacement of the remaining 70% of the heavy-duty diesel vehicle fleet. By combining all these possibilities (multiple mechanisms, multiple freight fleet

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[47] See table 2-3 in Chapter 2.

components) we could construct a substantial amount of different freight-related strategies[48].

It would be infeasible to evaluate all of the possible strategies that can be constructed. However, we can narrow the number of strategies to evaluate by analyzing the characteristics of each mechanism. For example, the literature indicates that retrofitting a heavy-gasoline truck using available technology does not yield considerable unit emissions reductions; thus we can discard retrofitting this type of vehicles in the strategies we construct. We could further narrow the number of strategies to evaluate by recalling that our objective in the planning process for freight transportation in the MCMA is the emissions reduction of key pollutants. These key pollutants include primarily particulate matter (PM_{10}) and nitrogen oxides (NO_x), and to a lesser extent non-methane hydrocarbons (NHMC). Diesel vehicles have the highest unit emissions of both PM_{10} and NO_x emissions, while heavy gasoline trucks have the highest unit emissions of NMHC; thus our strategies should have a stronger focus on these types of vehicles. Furthermore, we should capitalize on the knowledge gained throughout our analysis and evaluation of the strategies included in the PROAIRE. For instance, from that analysis we concluded that implementing and enforcing stricter emission standards for new heavy-duty diesel vehicles was effective in reducing PM_{10} emissions; thus, we should include it in the strategies we construct. Furthermore, we learned that more aggressive replacement and retrofit programs than the ones included in the PROAIRE were needed in order to achieve substantial emissions reductions. Therefore, the freight-related strategies we construct should be more aggressive in terms of the number of vehicles included in them and their deployment schedules.

Having this in mind, eight different freight-related strategies were constructed using the mechanisms described above. Most of these strategies include only one mechanism, in order to better estimate each mechanism's effectiveness in achieving substantial and sustained emissions reductions. These eight strategies, the mechanism(s) they employ, the pollutants at which they are aimed, as well as their deployment schedules and the number of vehicles included in them are shown in table 5-1.

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[48] For example, assuming 5 mechanisms and 2 different freight fleet components (gasoline freight fleet and diesel fleet) we could construct 32,767 different strategies.

Table 5-1 Vehicle Technology and Fuel Quality Improvements Strategies

Mechanism(s)	Strategy	Key Pollutant Reductions	Deployment Schedule	Number of vehicles included
• Stricter Emission Standards • Fuel Quality Improvements	**1.** Stricter Emission Standards for New Heavy-Duty Diesel Vehicles	NO_x PM10 NMHC	Starts: 2006 Ends: 2015	N/A
Fleet Renewal	**2.** All Heavy-Duty Diesel Vehicles Must be at Most 15 years old.	NO_x PM_{10}	Phase 1 : 2004-2010 Phase 2: 2011-2025	N/A
	3. All Light-Duty Gasoline Vehicles Must be at Most 15 years old.	NO_x NMHC	Phase 1 : 2004-2010 Phase 2: 2011-2025	N/A
	4. All Heavy-Duty Gasoline Vehicles Must be at Most 15 years old.	NO_x NMHC	Phase 1 : 2004-2010 Phase 2: 2011-2025	N/A
	5. Replacement of year 2000 and previous model heavy-duty diesel vehicles with new heavy-duty diesel vehicles.	NO_x PM_{10}	Starts: 2004 Ends: 2010	57,000
	6. Replacement of year 2000 and previous model heavy-duty gasoline vehicles with new heavy-duty gasoline vehicles.	NO_x NMHC	Starts: 2004 Ends: 2010	55,000
• Vehicle Engine Retrofits • Fuel Quality Improvements	**7.** All year 2000 and previous model heavy-duty diesel vehicles must have retrofit devices installed.	NO_x PM_{10} NMHC	Phase 1 : 2004-2010 Phase 2: 2011-2025	
• Vehicle Replacement based on Fuel Usage • Fleet Renewal	**8.** Replacement of year 2000 and previous model light-duty gasoline vehicles with new light-duty natural gas powered vehicles.	NO_x PM_{10} NMHC	Starts: 2004 Ends: 2010	230,000

The first strategy in table 5-1 is essentially the same as the first government strategy described in the MIT PROAIRE in Chapter Four. The deployment schedule for this strategy would gradually include a higher percentage of new heavy-duty diesel vehicle sales meeting stricter emission standards each year from 2006-2015. Starting in year 2015 all new heavy-duty diesel vehicles would meet EPA-2004 and EPA-2007 emission standards for NMHC, NO_x and PM_{10}. This strategy is also using indirectly the fuel quality improvement mechanism, since new heavy-duty diesel vehicles require the use of low sulphur diesel, which is not currently available in the MCMA, in order to meet EPA-2007 emission standards.

Strategies two through six use vehicle fleet renewal as a mechanism to achieve emissions reductions. Strategies two, three and four set a maximum age limit of 15 years old for heavy-duty diesel vehicles, heavy-duty gasoline vehicles and light-duty gasoline vehicles, respectively. Considering that the freight fleet in the MCMA is significantly older than 15 years old, especially for heavy-duty diesel vehicles, we cannot expect that all vehicles will meet the age limit immediately after it is set. Therefore, we should establish a transition period in which old vehicles will be renewed in order to meet the age requirement. Once the transition period ends, the age limit should be met by all vehicles included in the strategy. With this in mind, the deployment schedules for these strategies have been divided into two phases. The first phase would start in 2004 and 2010 and would be considered the transition period, while the second phase would begin in 2011 and continue until the end of the planning horizon (2025). It is during this second stage that all vehicles included in each strategy would have to meet the 15 year maximum age requirement.

Strategies five and six call for the replacement of year 2000 and previous model heavy-duty diesel vehicles with new heavy-duty diesel vehicles and heavy-duty gasoline vehicles with new heavy-duty gasoline vehicles, respectively. These replacements would be done gradually starting in 2004 and ending in 2010 including a total of 57,000 heavy-duty diesel vehicles and 55,000 heavy-duty gasoline vehicles. Recalling that these types of vehicles have the highest NHMC, NO_x and PM_{10} emission rates and that such emissions rates increase substantially as vehicles get older[49], the primary goal of these strategies is to aggressively remove from the MCMA freight fleet the oldest, most polluting heavy-duty diesel and gasoline vehicles by replacing with new and cleaner ones. By comparing strategy six with the third government strategy included in the

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[49] See table 2-6 in Chapter 2.

PROAIRE, we can see that the former includes more than double the amount of heavy-duty gasoline vehicles (57,000 vs. 27,000), thus making it considerably more aggressive.

Strategy seven uses vehicle engine retrofits as the primary mechanism to achieve emissions reductions. From our analysis in Chapter 4 of the diesel engine retrofit program included in the PROAIRE we concluded that it was not effective in achieving emissions reductions because it did not account for heavy-duty diesel vehicles entering the fleet without retrofit devices after the program ended. This gained knowledge was used in the construction of strategy seven. This strategy states that all 2000 and previous model year heavy-duty diesel vehicles that use the MCMA road network must have retrofit devices installed. By framing it in such a way, we can avoid having old heavy-duty diesel vehicles entering the MCMA in future years without retrofit devices. As with strategies two, three and four, strategy seven would have a transition period from 2004 through 2010 in which vehicles would gradually be retrofitted. Starting in 2011 all heavy-duty diesel vehicles using the MCMA road network will be required to have retrofit devices. The retrofit devices used in this strategy are the same as the ones presented in Chapter 4[50]. Strategy seven also uses the fuel quality improvement mechanism to achieve emissions reductions since diesel particulate filters require the availability and usage of low sulphur diesel[51] to function properly.

Strategy eight uses both vehicle fleet renewal and vehicle replacement based on fuel usage as mechanisms to achieve emissions reductions. This strategy calls for aggressively replacing year 2000 and previous model light-duty gasoline vehicle with new light-duty natural gas powered vehicles. It would begin in 2004 and end in 2010, replacing approximately 230,000 vehicles.

Having specified these eight freight-related strategies, we can move on to evaluating their effectiveness in achieving emissions reductions, as well as the cost of the MCMA freight fleet if they are implemented. Figure 5-1, 5-2 and 5-3 illustrate the cumulative NMHC, NO_x and PM_{10} freight emissions from year 2000 to 2025, as well as the emissions reductions/increments with respect to the base case for each strategy and all "future stories".

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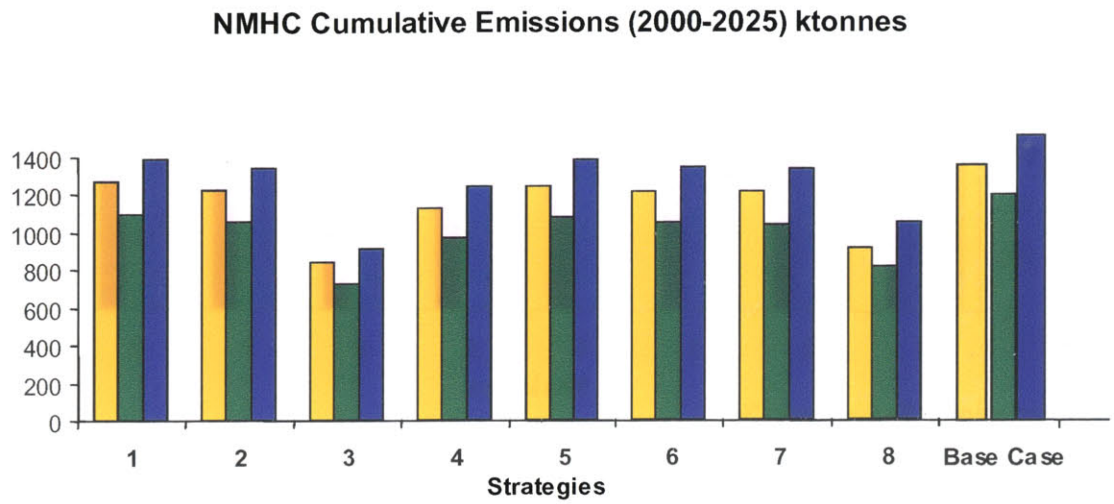
[50] See table 4-2 in Chapter 4.

[51] Less than 50 ppm.

Figure 5-1 NMHC Emissions and Emissions Reductions for Vehicle Technology and Fuel Quality Improvement Strategies



Emissions' Reductions (%)

DC	1%	5%	35%	12%	3%	5%	5%	29%
CC	1%	5%	34%	12%	2%	5%	6%	27%
GU	1%	5%	35%	12%	2%	5%	5%	25%

Note: 1) DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound"

From figure 5-1 we can note that strategy three would achieve the greatest freight-related NMHC emissions reductions (34%-35%), followed by strategies eight (25%-29%) and four (12%), respectively. All other strategies would achieve 5% or less freight-related NMHC emissions reductions; in fact, NMHC emissions reductions for strategies one and five can be considered negligible. The fact that strategy three has the greatest NMHC emissions reduction is not surprising, since it involves renewing the light-duty gasoline freight fleet, which includes the greatest amount of vehicles (58% of the entire MCMA freight fleet)[52].

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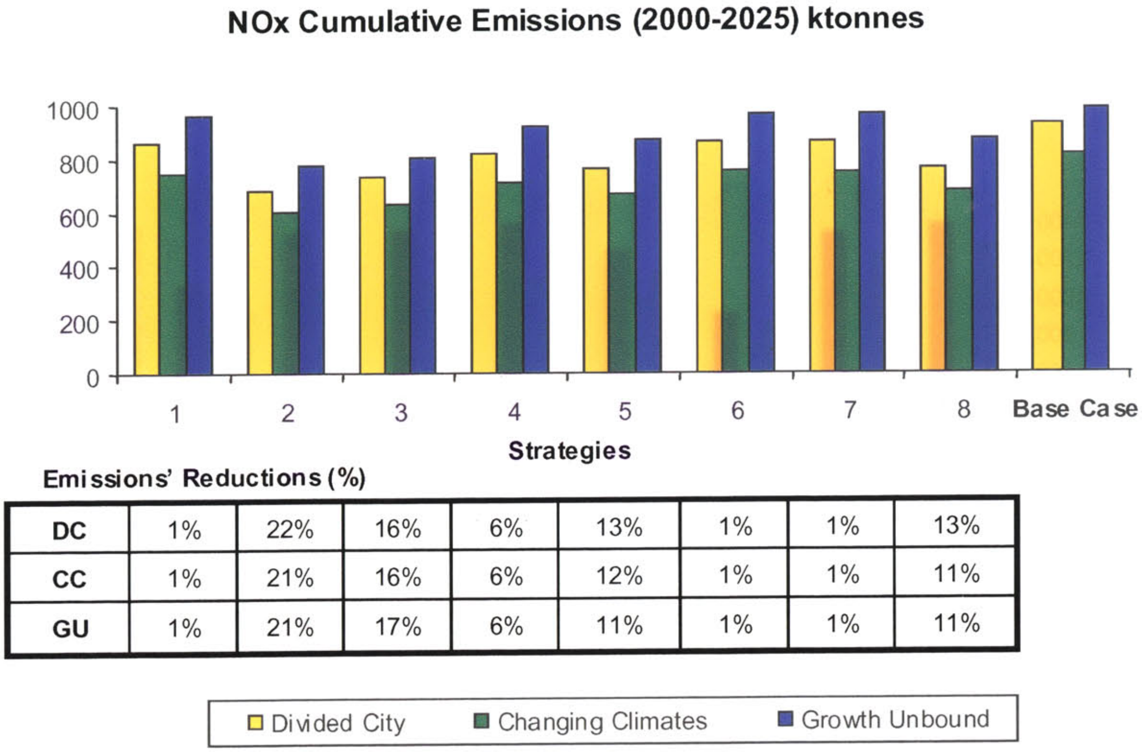
[52] See figure 2-2 in Chapter 2.

Figure 5-2 NO$_x$ Emissions and Emissions Reductions for Vehicle Technology and Fuel Quality Improvement Strategies

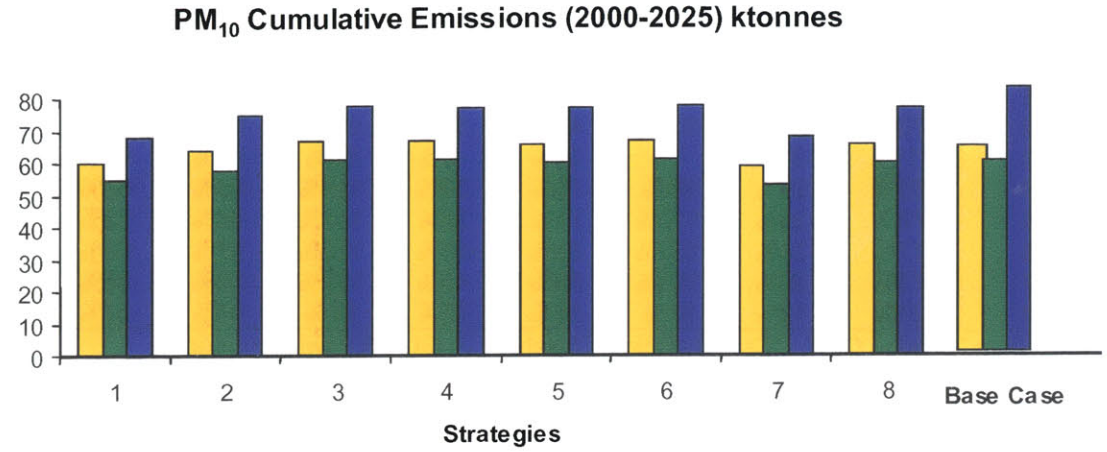


DC	1%	22%	16%	6%	13%	1%	1%	13%
CC	1%	21%	16%	6%	12%	1%	1%	11%
GU	1%	21%	17%	6%	11%	1%	1%	11%

Note: 1) DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound"

From figure 5-2 we can note that strategy two would achieve the greatest freight-related NO$_x$ emissions reductions (21%-22%). Strategies three (16%-17%), five (11-13%) and eight (11%-13%) would also achieve considerable freight-related emissions reductions, while emissions reductions for all other strategies would be less than 6%. NO$_x$ freight emissions reductions for strategies one, six and seven can be considered negligible.

Figure 5-3 PM_{10} Emissions and Total Freight Fleet Costs for Vehicle Technology and Fuel Quality Improvement Strategies



Emissions' Reductions (%)

DC	10%	4%	0%	0%	1%	0%	12%	1%
CC	10%	5%	0%	0%	2%	0%	13%	2%
GU	13%	4%	0%	1%	1%	0%	13%	1%

🟨 Divided City 🟩 Changing Climates 🟦 Growth Unbound

Note: 1) DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound"

From figure 5-3 we can note that strategies one (10%-13%) and seven (12%-13%) would achieve considerable freight-related PM_{10} emissions reductions (greater than 10%). Strategy two would achieve approximately a 5% reduction in freight-related PM_{10} emissions, while, strategies three and six would not achieve any reductions. Emissions reductions for strategies four, five and eight can be considered negligible.

Our analysis of each strategy should not only include cumulative emissions reductions, but also the level of such emissions in the future. A strategy might be able to achieve substantial emissions reduction in the short term, but incapable of maintaining low emissions levels in the medium and long term, thus making it undesirable. Therefore, we should compare emissions levels in the future under each strategy if it is implemented. Table 5-2 shows the percentage increase/decrease of year 2025 emission levels with respect to year 2000 emission levels for each of the strategies analyzed.

Table 5-2 Percentage Increase/Decrease of Year 2025 Emission Levels with Respect to Year 2000 for Vehicle Technology and Fuel Quality Improvement Strategies

Strategy	NMHC			NO_x			PM_{10}		
	DC	CC	GU	DC	CC	GU	DC	CC	GU
1	76%	32%	106%	81%	39%	115%	39%	16%	70%
2	70%	29%	101%	46%	15%	80%	91%	64%	147%
3	-11%	-35%	7%	29%	-2%	53%	95%	68%	151%
4	65%	25%	96%	79%	39%	115%	95%	68%	151%
5	78%	35%	110%	74%	36%	113%	96%	72%	157%
6	77%	34%	109%	89%	46%	126%	97%	69%	153%
7	73%	30%	103%	85%	43%	122%	59%	36%	107%
8	27%	12%	64%	58%	25%	97%	94%	67%	151%

Note: DC= "Divided City"; CC= "Changing Climates"; 3) GU= "Growth Unbound".

From table 5-2 we can take several things. First, emissions levels for all three pollutants in the year 2025 would be higher than those of year 2000 under all strategies and for all three future stories, except for NMHC and NO_x for strategy three; thus the growth in freight transportation demand (vehicle-km) under each future story would prevent nearly all strategies to achieve sustained emissions reductions. Second, strategy three would be capable of achieving up to a 35% decrease in NMHC emissions for two future stories ("Divided City" and "Changing Climates"), while having a 7% increase for the future story "Growth Unbound". As far as NO_x emission levels, it would only be capable of achieving a 2% decrease for the future story "Changing Climates". Therefore, this strategy would have the best performance with respect to future emissions levels of both NMHC and NO_x. Third, as far as PM_{10} emission levels, the least increase would occur under strategy one with an increase ranging from 16% to 70% depending on the future story, followed by strategy seven with an increase ranging from 36% to 107% depending on the future story.

Based on our analysis of each strategy's cumulative emissions reductions and future emissions levels we can see that no strategy if implemented would be capable of achieving substantial and sustained emissions reductions by itself under all three "future stories" considered. However, it could be possible to use several strategies to construct combinations that are capable of achieving both substantial and sustained emissions reductions. When choosing which strategies to include in the combinations to be constructed, we should consider each strategy's emissions reductions and emission levels for each pollutant, as well as the cost of the MCMA freight fleet if implemented.

Furthermore, we should also consider their robustness with respect to uncertainties posed by the "Future Stories", as well as unforeseen changes in their objectives, deployment schedules or compliance levels during their implementation.

The total costs of the MCMA freight fleet under each strategy have been estimated and are shown in table 5-3. From this table we can see that strategy five would have the highest costs if implemented, rising approximately 10% when compared to the Base Case. Strategy one would have the least increase in total costs if implemented (less than 1%). It is interesting to note that even when the light-duty gasoline freight fleet includes the greatest number of vehicles, the strategies that include this fleet component (strategies three and eight) would not cause the greatest increase in costs if implemented. In the case of strategy three (maximum age of light-duty gasoline vehicles must be 15 years) the costs would not rise as much because the vehicles in this freight fleet component already have an average age of approximately 10 years; thus the number of vehicles that would have to be replaced to meet the age requirements is not as great as would be the case for heavy-duty diesel or gasoline vehicles[53]. In the case of strategy eight, even though it includes the replacement of a substantial amount of vehicles (approximately 230,000), the cost of a new light-duty natural gas vehicle is considerably lower than that of a new heavy-duty diesel or heavy-duty gasoline vehicle[54]. Therefore, when compared to replacement strategies for these two vehicle types (strategies five and six) strategy eight would have a lower increase in costs if implemented.

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[53] The average age of the heavy-duty diesel freight fleet is 18 years old. See table 2-1 in Chapter 2.

[54] The cost of a new natural gas truck is assumed to be 180,000 Mexican Pesos (MXP), while the cost of a new heavy-duty diesel truck is assumed to be 1,000,000 MXP and that of a new heavy-duty gasoline truck 800,000 MXP.

Table 5-3 Total Costs of the MCMA Freight Fleet for Vehicle Technology and Fuel Quality Improvement Strategies

Strategy	Present Value of Total Costs of the MCMA Freight Fleet (2000-2025) in BYBMXP[1/]		
	Divided City	Changing Climates	Growth Unbound
Base Case	749	925	1,356
1	751 (0.3%)	927 (0.2%)	1,359 (0.2%)
2	803 (7.2%)	996 (7.7%)	1,456 (7.4%)
3	775 (3.5%)	960 (3.8%)	1,402 (3.4%)
4	781 (4.3%)	968 (4.6%)	1,415 (4.4%)
5	824 (10.0%)	1,022 (10.5%)	1,496 (10.3%)
6	806 (7.6%)	997 (7.8%)	1,458 (7.5%)
7	755 (0.8%)	931 (0.6%)	1,364 (0.6%)
8	797 (6.4%)	987 (6.7%)	1,444 (6.5%)

1/ Year 2000 Billion Mexican Pesos. The discount rates are: "Divided City" = 13%; "Changing Climates" = 10%; "Growth Unbound" = 8%[55].

Note: figures in parenthesis represent the percent increase in total costs with respect to the Base Case.

The costs of the MCMA's freight fleet under these strategies would be considerably high. When analyzing these strategies and discussing their economical feasibility it is important to determine who will bear such cost increments. For instance, if the vehicle fleet is renewed by setting a maximum age limit, freight vehicle owners (i.e. private companies) would have to invest a considerable amount of money to comply with it. These companies might not have the necessary financial resources needed to renew their fleet or, if they do, they might transfer these costs increments to their customers; thus, the end customers would ultimately fund their fleet renewal. It could also be possible for the government to invest public funds and subsidize the cost increments posed by each strategy to be implemented. These strategies would improve the freight transportation system in the MCMA, which would be beneficial for its residents and companies located in it. A viable freight transportation system would help sustain the

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[55] The discount rates are explained in Chapter 3

region's economic growth, while maintaining low negative effects, such as pollutant emissions. Therefore, since it is in the region's best interest to have a viable freight transportation system, these cost increments could also be met by both the public and private sectors. For instance, a program to finance the fleet renewal could be offered by the government to freight vehicle owners by which they are offered to low interest loans to purchase a new freight vehicle.

As seen from the figures and tables presented earlier, the ability to achieve emissions reductions, as well as the total cost of the MCMA freight fleet varies among strategies. Ideally, we would like to choose a strategy that has the capability of achieving the greatest emissions reductions and the lowest costs associated with it; however, not surprisingly, the strategies capable of achieving the greatest emissions reductions are not the ones with the lowest costs. In order to compare the effectiveness of each strategy we can construct a measure labeled cost-effectiveness by dividing each strategy's emissions reduction of each pollutant by the total cost of the MCMA freight fleet if implemented. The greater the value of a strategy's cost effectiveness for a particular pollutant, the more desirable it should be considered. Table 5-4 shows the cost effectiveness (estimated using the measure presented above) for all strategies and future stories for NMHC, NO_x and PM_{10} pollutants.

Table 5-4 Vehicle Technology and Fuel Quality Improvement Strategies' Cost Effectiveness (tonnes/BYBMXP[1/])

Strategy	NMHC			NO_x			PM_{10}		
	DC	CC	GU	DC	CC	GU	DC	CC	GU
1	13	10	10	13	10	10	9	6	7
2	77	50	45	237	158	138	4	3	2
3	572	396	353	183	130	121	0	0	0
4	201	136	115	67	48	40	0	0	1
5	42	26	22	140	90	72	1	1	1
6	83	57	45	11	8	5	0	0	0
7	91	66	56	17	12	10	10	8	7
8	473	298	247	141	86	73	1	1	1

Note: 1) DC= "Divided City"; CC= "Changing Climates"; 3) GU= "Growth Unbound".
1/ BYBMXP is equal to Year 2000 Billion Mexican Pesos.

From table 5-4 we can see that strategy three has the highest cost effectiveness when considering NMHC emissions, followed by strategy eight. For NO_x emissions, strategy two has the highest cost effectiveness, followed by strategy three. As far as PM_{10} emissions, strategies one and seven have the highest cost effectiveness.

As mentioned earlier, we are interested in strategies' robustness with respect to the uncertainties posed by the Future Stories. We can estimate such robustness by testing each strategies capability of achieving substantial and sustained emissions reductions under each Future Story. However, we are also interested in determining each strategy's robustness with respect to unforeseen changes in their objectives and compliance levels during their implementation. The robustness of each strategy with respect to its implementation is very relevant for our analysis if we consider the political structure of the MCMA. The implementation of all strategies being tested requires coordination between the governments of the Distrito Federal (DF), the Estado de Mexico and the Federal Government. If we further consider that currently three different political parties hold the executive powers of each of these governments it is not unreasonable to believe that any strategy might not be implemented as originally planned. In principle, we would like to choose those strategies whose capability of achieving emissions reductions is not reduced substantially if unforeseen changes in its objectives deployment schedule or compliance levels occur during its implementation.

Table 5-5 includes the changes we believe could occur during the implementation of each strategy. For strategy one, we are interested in testing its performance in case its deployment schedule extends beyond 2015, specifically up to 2020. Such a change could occur either because the government decides to modify the objective of the strategy or because vehicle manufacturers are not able to comply with the original deployment schedule.

For strategies two, three and four we are interested in testing their performance in case the 15 year old age limit is not respected and the real age limit extends up to 20 years old. This change could occur either because the government decides to extend the age limit before the strategy is actually implemented or during its implementation, or because vehicle owners do not comply with the age limit and even though they renew some of their vehicles, the age of these is actually up to 20 years old.

For strategies five and six, we are interested in determining their effectiveness in case not all vehicles originally planned are replaced. These changes could occur because the government decides to reduce the number of vehicles replaced before or during the strategy's implementation or because not all vehicle owners replace their vehicles.

The performance of strategy seven relies on two key factors. The first is related to the number of vehicles retrofitted and the second involves the effectiveness of the retrofit devices installed on vehicles. The number of vehicles being retrofitted can be different than the one originally planned either because the government decides to cut back on vehicle retrofits before or during the implementation or simply because vehicle owners do not install the retrofit devices on their vehicles' engines. The second key factor is related to the effectiveness of the retrofit devices installed on vehicles. Such effectiveness can be hampered for many reasons, including an improper installation; poor maintenance; the fuel used by the vehicle does not have the quality needed for the device to function properly; vehicle accidents, among others.

Therefore, we are interested in testing the strategy's effectiveness in case not all retrofit devices function properly.

Table 5-5 Vehicle Technology and Fuel Quality Improvement Strategies Changes in their Deployment Schedules and Objectives

Strategy	Implementation Changes
1. Stricter Emission Standards for New Heavy-Duty Diesel Vehicles	More lenient deployment schedule. Starts:2006 Ends:2020
2. All Heavy-Duty Diesel Vehicles Must be at Most 15 years old.	The maximum age increases to 20 years instead of 15 years.
3. All Heavy-Duty Gasoline Vehicles Must be at Most 15 years old.	The maximum age increases to 20 years instead of 15 years.
4. All Light-Duty Gasoline Vehicles Must be at Most 15 years old.	The maximum age increases to 20 years instead of 15 years.
5. Replacement of year 2000 and previous model heavy-duty diesel vehicles with new heavy-duty diesel vehicles.	Replacement of only a percentage of the amount of vehicles originally planned (i.e.10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90%).
6. Replacement of year 2000 and previous model heavy-duty gasoline vehicles with new heavy-duty gasoline vehicles.	Replacement of only a percentage of the amount of vehicles originally planned (i.e.10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%).
7. All year 2000 and previous model heavy-duty diesel vehicles must have retrofit devices installed.	**a.** Only a certain percentage (i.e.10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%) of all vehicles originally planned are retrofitted. **b.** Retrofit devices do not function properly due to lack of maintenance. **c.** Both events a and b occur.
8. Replacement of year 2000 and previous model light-duty gasoline vehicles with new light-duty natural gas powered vehicles.	Replacement of only a percentage of the amount of vehicles originally planned (i.e.10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%).

Table 5-6 shows the percentage decrease of each strategies one, two, three and four emissions reduction capability when accounting for the changes in their implementation mentioned above. From it we can see that the capability of achieving emissions reductions of strategies two, three and four would not suffer considerably if not implemented as planned for NHMC and NOx emissions and for all future stories considered.

Table 5-6 Percentage Decrease of Strategies One, Two, Three and Four Emissions Reductions Capability

Strategy	Changes	NMHC			NO_x			PM_{10}		
		DC	CC	GU	DC	CC	GU	DC	CC	GU
1	More Lenient Schedule	30%	33%	36%	60%	56%	64%	29%	17%	20%
2	Maximum age 20 years	11%	14%	26%	12%	13%	20%	33%	33%	33%
3	Maximum age 20 years	23%	23%	24%	34%	34%	33%	-	-	-
4	Maximum age 20 years	10%	11%	10%	15%	17%	16%	-	-	-

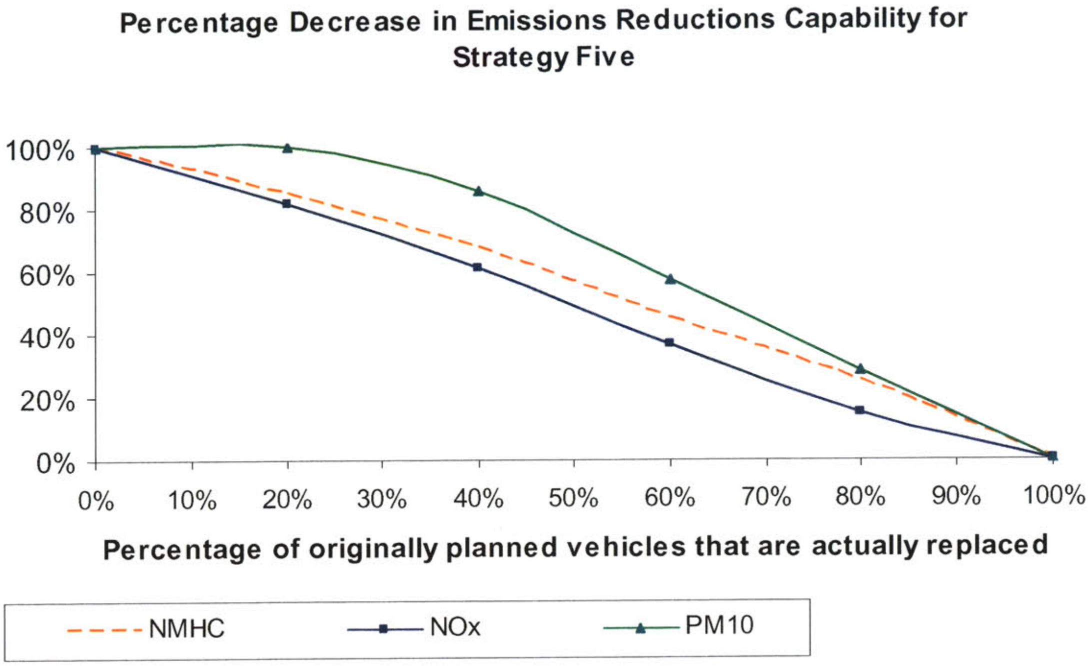
Notes: 🟨 0%-20% reduction ⬜ 21%-50% reduction 🟧 51%-100% reduction

Empty cells mean that there were no emissions reductions for that pollutant before the implementation changes.

Strategy one if implemented as originally conceived would be capable of achieving up to a 13% in PM_{10} emissions reductions and practically negligible reductions for NMHC and NO_x. If we include the changes in its implementation described above, its PM_{10} emissions reduction capability would suffer up to a 29% decrease.

Figures 5-4 through 5-9 illustrate the decrease in NMHC, NOx and PM_{10} emissions reductions capability in case strategies five, six, seven or eight are not implemented as originally planned.

Figure 5-4 Percentage Decrease of Strategy Five's Emissions Reductions Capability

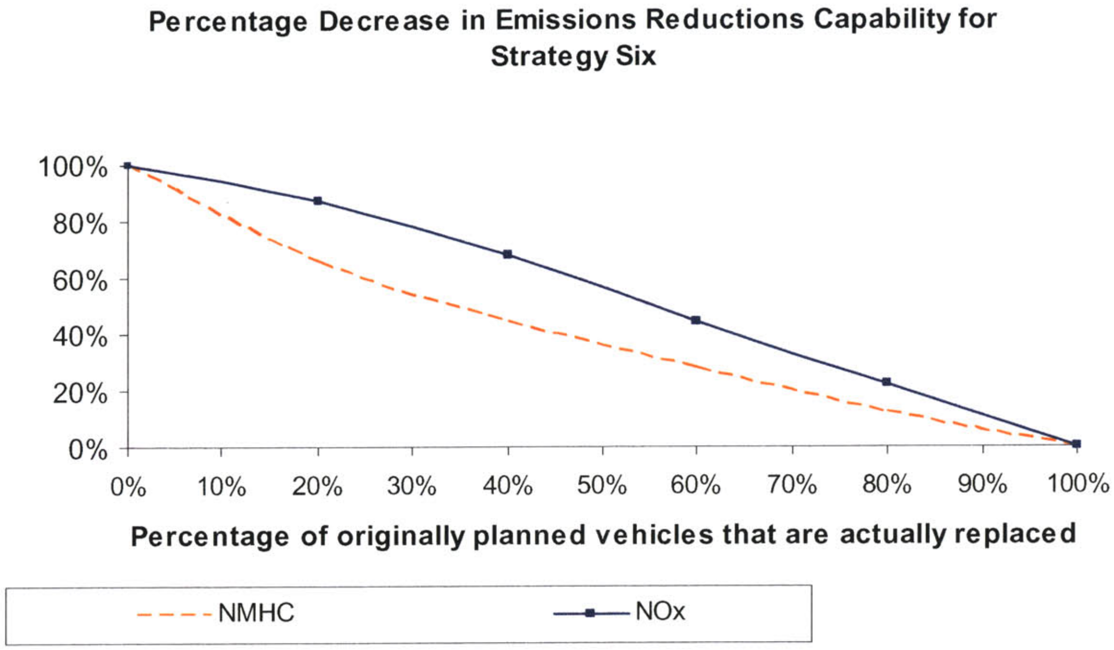


Note: Figures are for Future Story "A Divided City"

From figure 5-4 we can note that strategy five's emissions reduction capability for all three pollutants would decrease depending on the number of vehicles that are replaced; however, such decrease would not be linear for all three pollutants. For instance, if only 80% of the originally planned amount of vehicles is actually replaced, strategy five's NMHC, NO_x and PM_{10} emissions reductions capability would decrease by 25%, 15% and 29%, respectively. These nonlinearities are mainly attributable to the fact that emission rates (grams/mile) vary among different model year vehicles in a nonlinear manner and the fact that we are replacing vehicles of different ages (i.e. different model year) with newer ones. In general, older vehicles remain in the vehicle fleet a lesser amount of time than newer vehicles; however, the relationship between a vehicle's age and the amount of time it will remain in the vehicle fleet is nonlinear as well.

It is also interesting to note that in the case of PM_{10} emissions, no emissions reductions would be achieved if less than 20% of the originally planned vehicles were replaced.

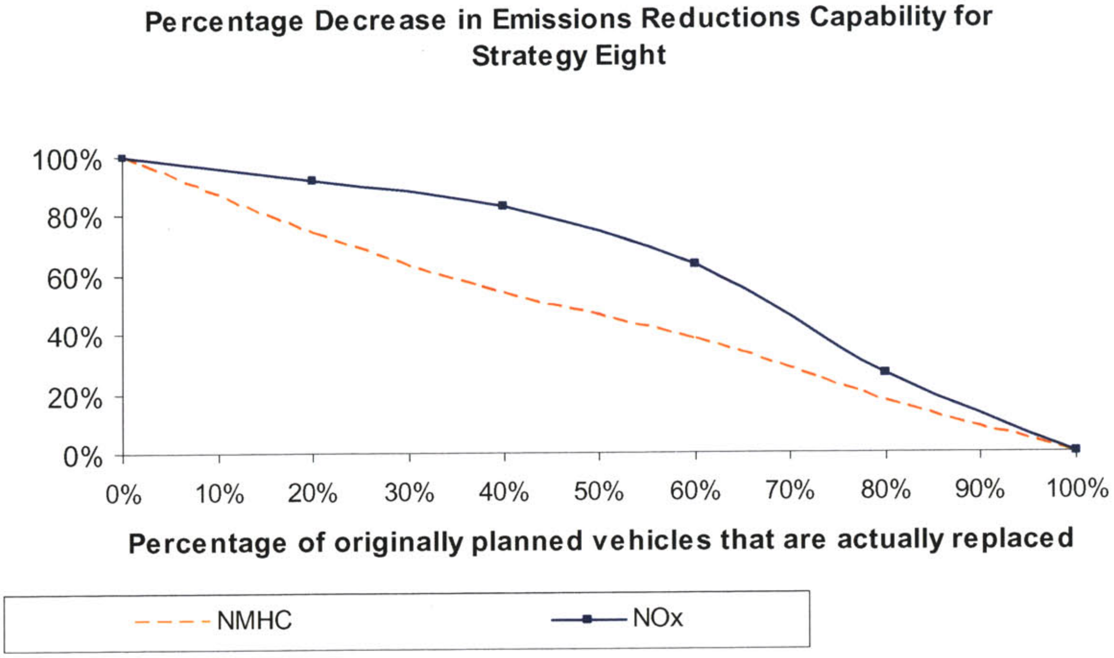
Figure 5-5 Percentage Decrease of Strategy Six's Emissions Reductions Capability



Note: Figures are for Future Story "A Divided City"

From this figure we can note that strategy six's capability of achieving NMHC and NO_x emissions reductions would decrease nonlinearly with respect to the percentage of the originally planned vehicles that are actually replaced. More specifically, for every percentage reduction in the number of vehicles that are actually replaced, strategy six's capability of achieving NO_x emissions reductions would decrease by more than a percentage point. If we focus on NMHC emissions, we can see the opposite behavior, for every percent decrease in the number of vehicles that are actually replaced we would get less than a one percent decrease in emissions reductions capability.

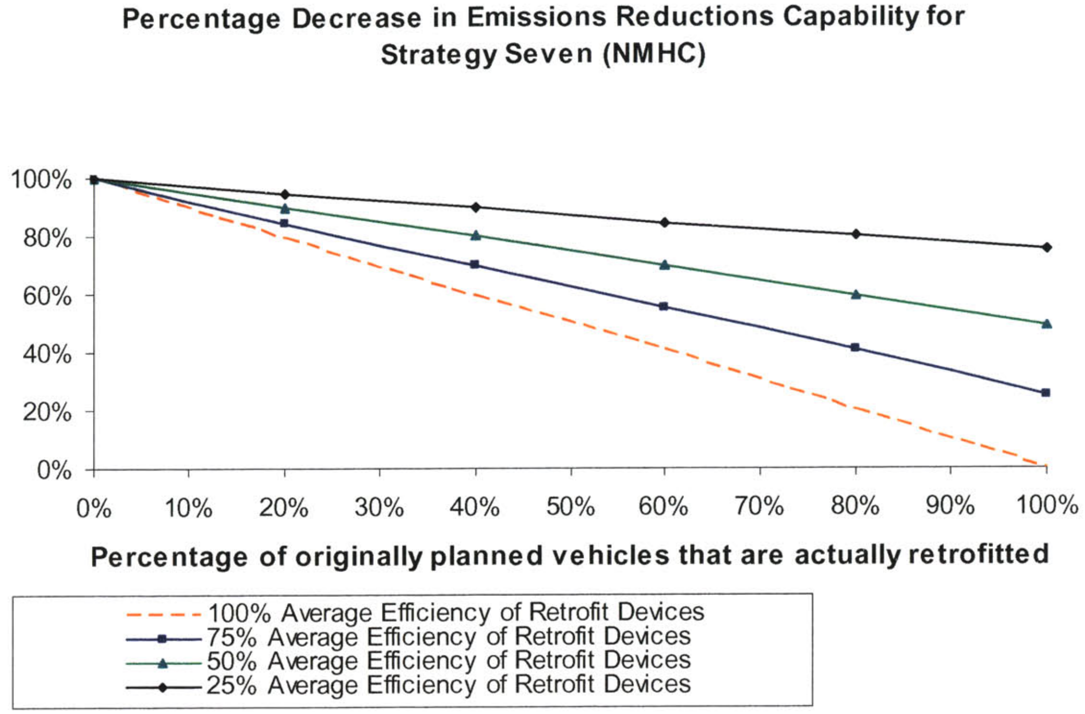
Figure 5-6 Percentage Decrease of Strategy Eight's Emissions Reductions Capability



Note: Figures are for Future Story "A Divided City"

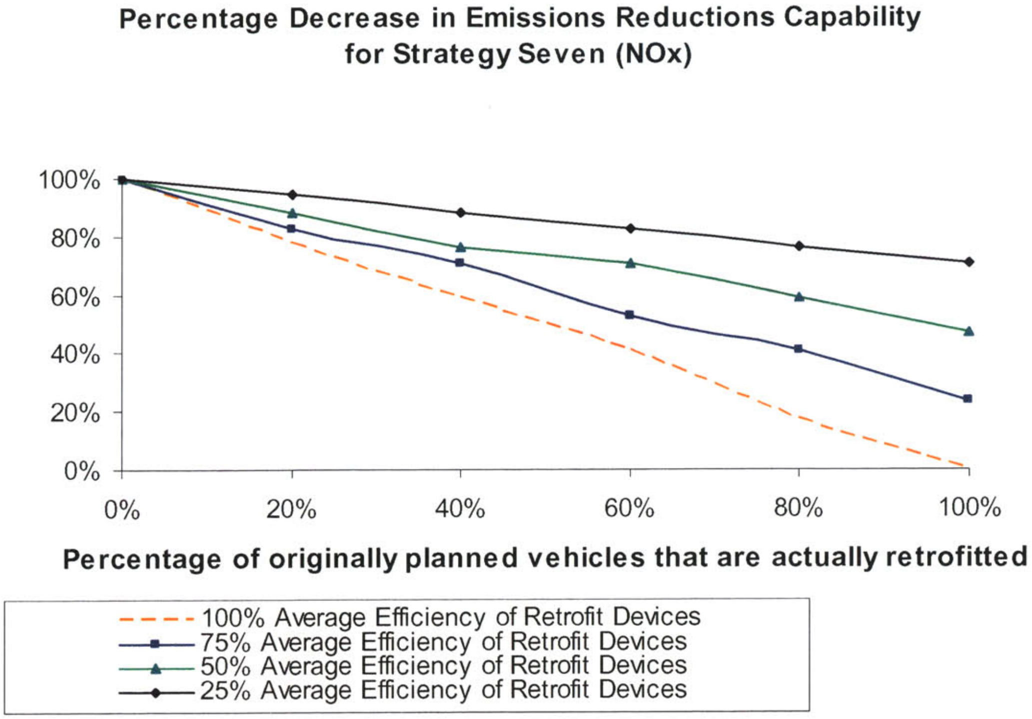
From this figure we can note that similarly to strategy six, strategy eight's capability of achieving NMHC emissions would decrease less than one percent for every percentage reduction in the number of vehicles that are actually replaced; however, if we focus on NO_x emissions, we can note that a decrease in the percentage of originally planned vehicles that are actually replaced would be followed with a greater decrease in strategy eight's capability of achieving substantial emissions reductions. We did not include PM_{10} emissions, since this strategy would practically achieve no emissions reductions for this pollutant even if implemented perfectly.

Figure 5-7 Percentage Decrease of Strategy Seven's NMHC Emissions Reductions Capability



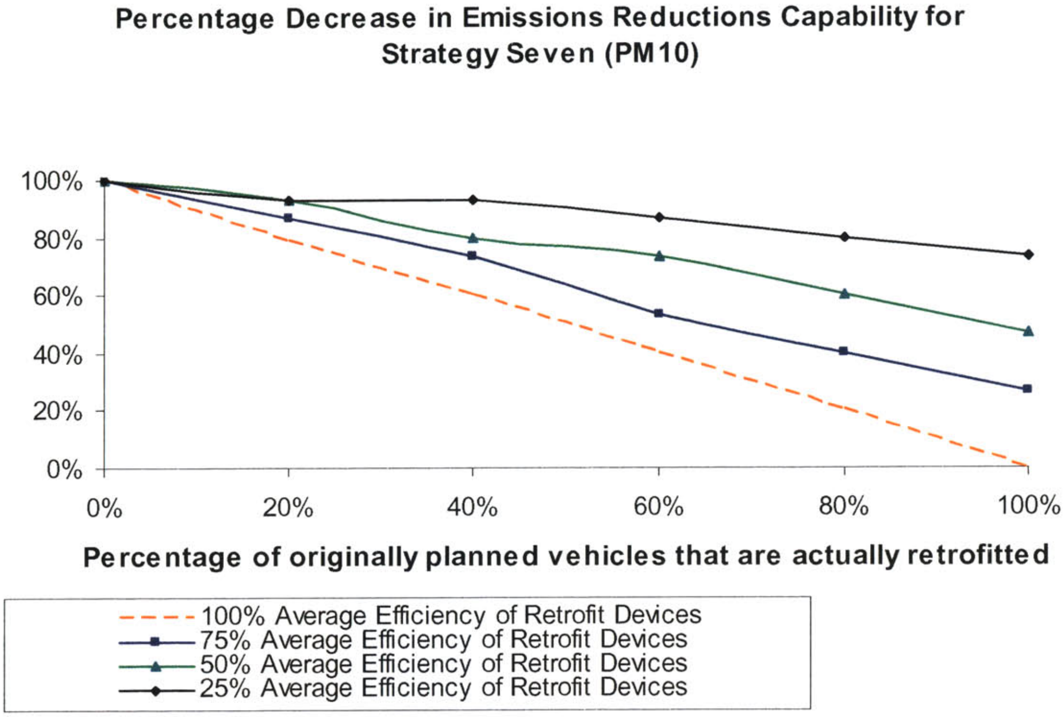
From figure 5-7 we can see that strategy seven's capability of achieving NMHC emissions reductions would vary depending on the average efficiency of retrofit devices, as well as the percentage of originally planned vehicles that are actually retrofitted. From it we can note that a combination of low values of the efficiency of retrofit devices and low percentages of vehicles retrofitted will produce considerably high decreases in strategy seven's capability of achieving NMHC emissions reductions.

Figure 5-8 Percentage Decrease of Strategy Seven's NO_x Emissions Reductions Capability



From figure 5-8 we can note that similarly to NMHC, strategy seven's capability of achieving substantial emissions reductions would be severely undermined if retrofit devices do not work properly or a considerable amount of vehicles are retrofitted.

Figure 5-9 Percentage Decrease of Strategy Seven's NO_x Emissions Reductions Capability



From figure 5-9 we can note that strategy eight's PM_{10} emissions reductions capability would decrease significantly if retrofit devices do not function properly or a low percentages of vehicles are actually retrofitted.

Our previous analysis had shown that this strategy was capable of achieving a 13% reduction in freight-related PM_{10} emissions; however, these reductions could be severely undermined if the strategy is not implemented as planned; thus making it less attractive than originally thought.

Throughout our analysis of the eight vehicle technology and fuel quality improvement strategies presented earlier we have estimated their capability of achieving emissions reductions that are sustainable in the future, the costs of the MCMA freight fleet if they are implemented, as well as their performance with possible changes in their implementation. Tables 5-7, 5-8 and 5-9 include a summary of the results of our analysis of each strategy.

Table 5-7 Vehicle Technology and Fuel Quality Improvement Strategies' Performance for NMHC

Strategy	Emissions Reductions with Respect to Base Case	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000	Percentage Increase of Total Costs with Respect to Base Case	Cost Effectiveness (tonnes/BYBMXP[1/])	Percentage Decrease of Emissions Reductions with Respect to Changes in the Implementation
1	1%	32%-106%	0.2%-0.3%	10-13	30%-36%
2	5%	29%-101%	7.2%-7.7%	45-77	11%-26%
3	34%-35%	(35%)-7%	3.4%-3.8%	353-572	23%-25%
4	12%	25%-96%	4.3%-4.6%	115-201	10%-11%
5	2%-3%	35%-110%	10.0%-10.5%	22-42	More than proportionately
6	5%	34%-109%	7.5%-7.8%	45-83	Less than proportionately
7	5%-6%	30%-103%	0.6%-0.8%	56-91	Proportionately to retrofit device's efficiency and the number of vehicles retrofitted
8	25%-29%	12%-64%	6.4%-6.7%	247-473	Less than proportionately

1/ BYBMXP is equal to Year 2000 Billion Mexican Pesos.

Notes: 1) Figures in parenthesis represent negative values; 2) **More than proportionately** means that a 1% decrease in the number of vehicles replaced or retrofitted will cause *more* than a 1% decrease in the strategy's emissions reduction capability. 3) **Less than proportionately** means that a 1% decrease in the number of vehicles replaced or retrofitted will cause *less* than a 1% decrease in the strategy's emissions reduction capability.

From table 5-7 we can note that in terms of NMHC, strategy three, four and eight would have the best overall performance if implemented. Strategy three would be capable of achieving the greatest emissions reductions, as well as the greatest decrease in future emission levels.

Table 5-8 Vehicle Technology and Fuel Quality Improvement Strategies' Performance for NO_x

Strategy	Emissions Reductions with Respect to Base Case	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000	Percentage Increase of Total Costs with Respect to Base Case	Cost Effectiveness (tonnes/BYBMXP[1/])	Percentage Decrease of Emissions Reductions with Respect to Changes in the Implementation
1	1%	39%-115%	0.2%-0.3%	10-13	56%-60%
2	21%-22%	15%-80%	7.2%-7.7%	138-237	12%-20%
3	16%-17%	(2%)-53%	3.4%-3.8%	121-183	33%-34%
4	6%	39%-115%	4.3%-4.6%	40-67	15%-17%
5	11%-13%	36%-113%	10.0%-10.5%	72-140	Less than proportionately
6	1%	46%-126%	7.5%-7.8%	5-11	More than proportionately
7	1%	43%-122%	0.6%-0.8%	10-17	Proportionately to retrofit device's efficiency and the number of vehicles retrofitted
8	11%-13%	25%-97%	6.4%-6.7%	73-141	More than proportionately

1/ BYBMXP is equal to Year 2000 Billion Mexican Pesos.

Notes: 1) Figures in parenthesis represent negative values; 2) **More than proportionately** means that a 1% decrease in the number of vehicles replaced or retrofitted will cause *more* than a 1% decrease in the strategy's emissions reduction capability. 3) **Less than proportionately** means that a 1% decrease in the number of vehicles replaced or retrofitted will cause *less* than a 1% decrease in the strategy's emissions reduction capability.

As far as NO_x emissions, table 5-8 shows that strategies two and three would have the best overall performance. Strategy two would be capable of achieving up to a 22% reduction in freight-related NO_x emissions. We can also note that no strategy would be capable of achieving sustained emissions reductions for all three future stories because of the growth of freight traffic in the MCMA. Strategy two would also have cost-effectiveness of these eight strategies.

Table 5-9 Vehicle Technology and Fuel Quality Improvement Strategies' Performance for PM_{10}

Strategy	Emissions Reductions with Respect to Base Case	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000	Percentage Increase of Total Costs with Respect to Base Case	Cost Effectiveness (tonnes/BYBM XP[1/])	Percentage Decrease of Emissions Reductions with Respect to Changes in the Implementation
1	10%-13%	16%-70%	0.2%-0.3%	7-9	17-29%
2	4%-5%	64%-147%	7.2%-7.7%	2-4	33%-100%
3	0%	68%-151%	3.4%-3.8%	0	-
4	0%-1%	68%-151%	4.3%-4.6%	0-1	-
5	1%-2%	72%-157%	10.0%-10.5%	1	More than proportionately
6	0%	69%-153%	7.5%-7.8%	0	-
7	12%-13%	36%-107%	0.6%-0.8%	7-10	Proportionately to retrofit device's efficiency and the number of vehicles retrofitted
8	1%-2%	67%-151%	6.4%-6.7%	1	-

1/ BYBMXP is equal to Year 2000 Billion Mexican Pesos.

Notes: 1) Figures in parenthesis represent negative values; 2) **More than proportionately** means that a 1% decrease in the number of vehicles replaced or retrofitted will cause *more* than a 1% decrease in the strategy's emissions reduction capability. 3) **Less than proportionately** means that a 1% decrease in the number of vehicles replaced or retrofitted will cause *less* than a 1% decrease in the strategy's emissions reduction capability.

Table 5-9 shows that strategy one is the best performing strategy when considering PM_{10} emissions. Strategies one and three would be capable of achieving up to a 13% reduction in freight-related PM_{10} emissions reductions. Their cost-effectiveness would be practically the same (7-10); however, strategy seven's performance could be severely undermined when considering the changes in its implementation.

5.4 Combined Vehicle Technology and Fuel Quality Improvement Strategies

As mentioned earlier, our analysis has shown that no strategy if implemented would be capable of achieving substantial and sustained emissions reductions by itself under all three "future stories" considered. However, it could be possible to construct combinations of strategies that are capable of achieving both substantial and sustained emissions reductions for key pollutants NMHC, NO_x and PM_{10}. Using the strategies presented in section 5.3 we have constructed five different combined strategies, which are shown in table 5-10.

The benefits in terms of emissions reductions, as well as costs of these combined strategies will not always be determined as the sum of the emissions reductions or costs attributable to each individual strategy. For instance, combined strategy one includes the implementation of stricter emission standards for new heavy-duty diesel vehicles, as well as setting a maximum age limit of 15 years for this type of vehicles. By combining these two strategies we would get a greater emissions reductions than the sum of each of these individual strategies emissions reductions because the setting an age limit would increase the number of new heavy-duty diesel vehicles entering the freight fleet which would have lower emission rates.

The benefits of other combined strategies in terms of emissions reductions have been estimated as the addition of each individual strategies emission reductions capability. For instance, combined strategy two includes setting a maximum age limit of 15 years for heavy-duty gasoline vehicles, while replacing year 2000 and previous model light-duty gasoline vehicles with new light-duty natural gas vehicles. Since each individual strategy is aimed towards a different freight fleet component, its combined benefits will be the sum of each strategy's benefits.

Table 5-10 Combined Vehicle Technology and Fuel Quality Improvement Strategies

Combined Strategies	Strategies Included	Key Pollutant Reductions	Deployment Schedule	Number of vehicles included
1	Stricter Emission Standards for New Heavy-Duty Diesel Vehicles	NO_x PM_{10} NMHC	Starts: 2006 Ends: 2015	N/A
	All Heavy-Duty Diesel Vehicles Must be at Most 15 years old.	NO_x PM_{10}	Starts: 2004 Ends: 2010	N/A
2	All Heavy-Duty Gasoline Vehicles Must be at Most 15 years old.	NO_x NMHC	Starts: 2004 Ends: 2010	N/A
	Replacement of year 2000 and previous model light-duty gasoline vehicles with new light-duty natural gas powered vehicles.	NO_x NMHC	Starts: 2004 Ends: 2010	230,000
3.	All Light-Duty Gasoline Vehicles Must be at Most 15 years old.	NO_x NMHC	Starts: 2004 Ends: 2010	N/A
	All Heavy-Duty Gasoline Vehicles Must be at Most 15 years old.	NO_x NMHC	Starts: 2004 Ends: 2010	N/A
4.	Stricter Emission Standards for New Heavy-Duty Diesel Vehicles	NO_x PM_{10} NMHC	Starts: 2006 Ends: 2015	N/A
	All Heavy-Duty Diesel Vehicles Must be at Most 15 years old.	NO_x PM_{10}	Starts: 2004 Ends: 2010	N/A
	All Heavy-Duty Gasoline Vehicles Must be at Most 15 years old.	NO_x NMHC	Starts: 2004 Ends: 2010	N/A
	Replacement of year 2000 and previous model light-duty gasoline vehicles with new light-duty natural gas powered vehicles.	NO_x NMHC	Starts: 2004 Ends: 2010	230,000
5.	Stricter Emission Standards for New Heavy-Duty Diesel Vehicles	NO_x PM_{10} NMHC	Starts: 2006 Ends: 2015	N/A
	All Heavy-Duty Diesel Vehicles Must be at Most 15 years old.	NO_x PM_{10}	Starts: 2004 Ends: 2010	N/A
	All Light-Duty Gasoline Vehicles Must be at Most 15 years old.	NO_x NMHC	Starts: 2004 Ends: 2010	N/A
	All Heavy-Duty Gasoline Vehicles Must be at Most 15 years old.	NO_x NMHC	Starts: 2004 Ends: 2010	N/A

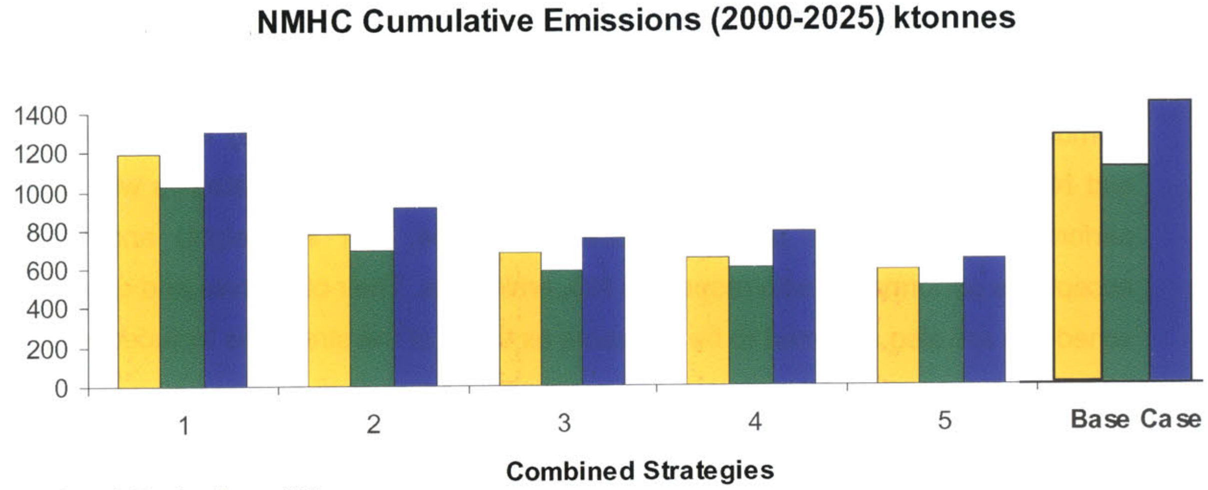
Combined strategy one is aimed primarily at reducing PM_{10} emissions and NO_x emissions to a lesser extent; thus it includes the best performing strategies for PM_{10} (strategies one and two) and NO_x (strategy two). Its objectives and deployment schedules are assumed to be the same as those of the strategies included in it.

Combined strategies two and three are aimed primarily at reducing NMHC emissions and NO_x emissions to a lesser extent; thus they including the strategies with a good performance for NMHC pollutants (strategies three, four and eight) and with an acceptable performance with respect to NO_x emissions. Their objectives and deployment schedules are also assumed to be the same as those of the strategies included in them.

Combined strategies four and five are the most aggressive of all. They are aimed towards reducing emissions for all three key pollutants. Both combined strategies include the best performing strategies for PM_{10} (strategies one and two), as well as for NO_x (strategy two). As far as NMHC, combined strategy four includes strategy four and combined strategy five includes the best performing strategy (strategy three). Their objective and deployment schedules are assumed to be the same as those of the strategies included in them. Combined strategy five can be viewed as the combination of the best performing strategies for each pollutant.

Having specified all five combined strategies we can now estimate their effectiveness in achieving emissions reductions for all three pollutants. Figures 5-10, 5-11 and 5-12 illustrate the cumulative emissions from year 2000 until 2025, as well as the percentage reduction for each combined strategy.

Figure 5-10 NMHC Emissions and Total Freight Fleet Costs for Combined Vehicle Technology and Fuel Quality Improvement Strategies



Emissions' Reductions (%)

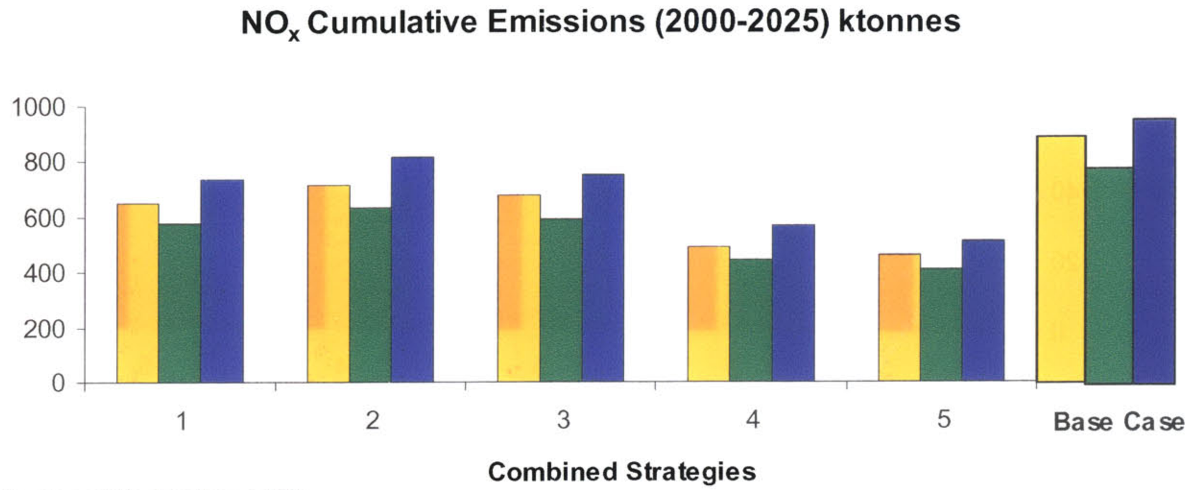
DC	7%	39%	47%	49%	54%
CC	7%	37%	46%	46%	53%
GU	7%	35%	47%	44%	54%

🟨 Divided City 🟩 Changing Climates 🟦 Growth Unbound

Note: DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound"

From figure 5-10 we can note two main things. First, that all combined strategies, except the first one, would achieve substantial freight-related emissions reductions (greater than 35%) if implemented. Second, that combined strategy five, if implemented, would achieve up to a 54% in freight-related NMHC emissions when compared to the base case.

Figure 5-11 NO_x Emissions and Total Freight Fleet Costs for Combined Vehicle Technology and Fuel Quality Improvement Strategies



Emissions' Reductions (%)

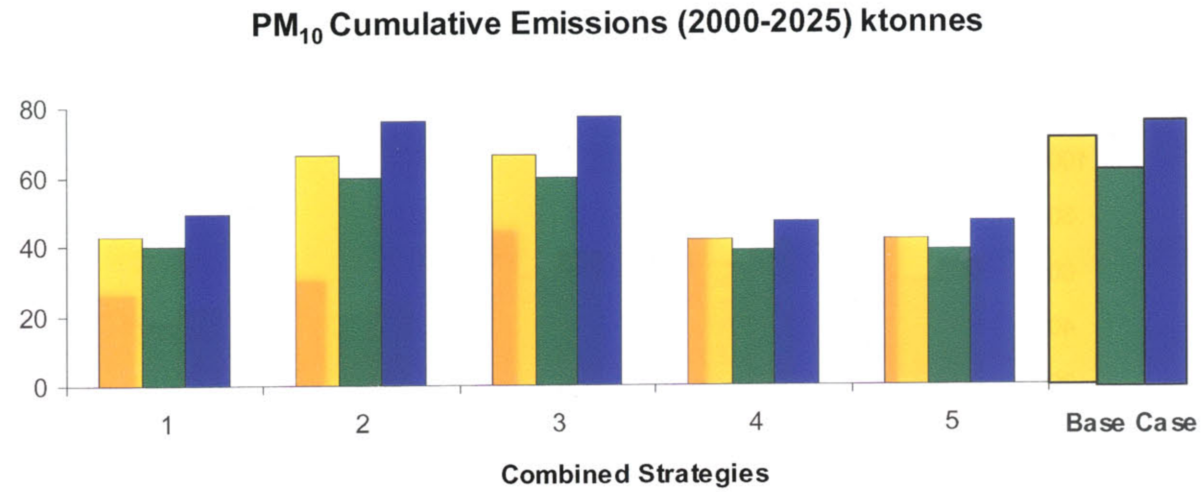
DC	25%	18%	22%	44%	47%
CC	24%	16%	22%	41%	47%
GU	25%	16%	23%	41%	48%

🟨 Divided City 🟩 Changing Climates 🟦 Growth Unbound

Note: DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound"

From figure 5-11 we can note that all combined strategies, except the second, could achieve freight-related NO_x emissions reductions greater than 20% when compared to the base case. Furthermore, such emissions reduction could be greater if either combined strategies four or five are implemented.

Figure 5-12 PM_{10} Emissions and Total Freight Fleet Costs for Combined Vehicle Technology and Fuel Quality Improvement Strategies



Emissions' Reductions (%)

DC	36%	1%	1%	37%	37%
CC	34%	2%	2%	36%	36%
GU	37%	3%	1%	40%	40%

🟨 Divided City 🟩 Changing Climates 🟦 Growth Unbound

Note: DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound"

Figure 5-12 shows that combined strategies one, four and five could achieve freight-related emissions reductions of approximately 35% for PM_{10} if implemented. Combined strategies two and three would practically have negligible emissions reductions for this particular pollutant.

Similarly to the analysis of the vehicle technology and fuel quality improvement strategies, in order to determine these combined strategies' capability of achieving sustained emissions reductions we have estimated the level of emissions for each pollutant in the year 2025 and compared it to its level in the year 2000, as shown in table 5-11.

Table 5-11 Percentage Increase/Decrease of Year 2025 Emission Levels with Respect to Year 2000 for Combined Vehicle Technology and Fuel Quality Improvement Strategies

Combination	NMHC			NO_x			PM_{10}		
	DC	CC	GU	DC	CC	GU	DC	CC	GU
1	57%	17%	83%	22%	-6%	48%	-73%	-77%	-66%
2	15%	-9%	51%	51%	20%	90%	93%	66%	149%
3	-26%	-46%	-11%	20%	-9%	43%	94%	67%	150%
4	-12%	-30%	-5%	-18%	-33%	11%	-77%	-80%	-70%
5	-50%	-65%	-40%	-46%	-60%	-34%	-76%	-79%	-69%

Note: DC= “Divided City”; CC= “Changing Climates”; 3) GU= “Growth Unbound”.

From this table we can make several observations. The first and probably most important is that the emissions reductions that can be achieved through some of these combined strategies would not only be substantial, but also sustained. For instance, combined strategy four if implemented would have emissions lower emission levels in the year 2025 than in the year 2000 for almost all future stories and pollutants, while combined strategy five’s 2025 emissions levels would be lower than in the year 2000 for all pollutants and future stories. Recalling that combined strategy one was aimed primarily towards reducing PM_{10} emissions, we can see from the above table that emission levels for this pollutant in 2025 could be up to 77% lower than their level in year 2000. Meanwhile, strategy two would only have lower 2025 emission levels than in year 2000 for NHMC under the “Changing Climates” future story. Strategy three would achieve lower emissions levels in year 2025 for NMHC for all future stories and NO_x for the future story “Changing Climates”.

Our analysis shows that substantial and sustained emissions reductions can be achieved if some of the combined strategies we are analyzing are implemented. However, these combined strategies would also increase the total costs of the MCMA fleet, as shown in table 5-12.

Table 5-12 Total Costs of the MCMA Freight Fleet for Vehicle Technology and Fuel Quality Improvement Strategies

Combined Strategy	Present Value of Total Costs of the MCMA Freight Fleet (2000-2025) in BYBMXP[1/]		
	Divided City	Changing Climates	Growth Unbound
Base Case	749	925	1,356
1	805 (7.5%)	997 (7.8%)	1,457 (7.4%)
2	798 (6.6%)	982 (6.2%)	1,439 (6.1%)
3	808 (7.9%)	1,003 (8.4%)	1,458 (7.5%)
4	847 (13.1%)	1,054 (13.9%)	1,518 (11.9%)
5	863 (15.2%)	1,075 (16.2%)	1,557 (14.8%)

1/ Year 2000 Billion Mexican Pesos. The discount rates are: "Divided City" = 13%; "Changing Climates" = 10%; "Growth Unbound" = 8%.

From this table we can note that combined strategy five, while having the greatest emissions reductions, would also have the greatest increase in costs, approximately 15% with respect to the base case. Combined strategy four would have the second greatest increase in costs (approximately 13%), followed by combined strategies three, one and two, respectively.

These cost increments are substantially high; thus, as mentioned earlier, when discussing their economically feasibility it is necessary to determine who will bear such cost increments. Similarly to the individual vehicle technology and fuel quality improvement strategies, the costs increments of these strategies could be met by the either the private or public sector solely or by both of them; however, given the magnitude of these cost increments, it does not seem reasonable to have private companies bear them by themselves. Thus, programs promoted and backed by the government to finance these costs increments could be put in place in order to improve the freight transportation system in the MCMA.

Recalling that any strategy might not be implemented as originally planned, we should also estimate the performance of the combined strategies under unforeseeable changes in their implementation. Since these new strategies are combinations of some of our previous eight strategies, the implementation changes of each combined strategy consist of the changes in the implementation of the original strategies included in them, as shown in table 5-13.

Table 5-13 Combined Vehicle Technology and Fuel Quality Improvement Strategies Changes in their Deployment Schedules and Objectives

Combined Strategies	Implementation Changes
1	**a.** More lenient deployment schedule. Starts:2006; Ends:2020 **b.** The maximum age for heavy-duty diesel vehicles increases to 20 years instead of 15 years.
2	**a.** The maximum age for heavy-duty gasoline vehicles increases to 20 years instead of 15 years. **b.** Replacement of a less amount of light-duty gasoline vehicles for natural gas vehicles originally planned (i.e. 10%, 20%, 30%,...,90%)
3	**a.** The maximum age for light-duty gasoline vehicles increases to 20 years instead of 15 years. **b.** The maximum age for heavy-duty gasoline vehicles increases to 20 years instead of 15 years.
4	**a.** More lenient deployment schedule. Starts:2006; Ends:2020 **b.** The maximum age for heavy-duty diesel vehicles increases to 20 years instead of 15 years. **c.** The maximum age for heavy-duty gasoline vehicles increases to 20 years instead of 15 years. **d.** Replacement of a less amount of light-duty gasoline vehicles for natural gas vehicles originally planned (i.e. 10%, 20%, 30%,...,90%)
5	**a.** More lenient deployment schedule. Starts:2006; Ends:2020 **b.** The maximum age for heavy-duty diesel vehicles increases to 20 years instead of 15 years. **c.** The maximum age for light-duty gasoline vehicles increases to 20 years instead of 15 years. **d.** The maximum age for heavy-duty gasoline vehicles increases to 20 years instead of 15 years.

The capability of achieving emissions reductions of combined strategies one, three and five would not be decreased substantially when considering changes in their implementation. In fact, none of these combined strategies would suffer a decrease in emissions reductions greater than 50% for the key pollutants it is aimed at, as shown in table 5-14.

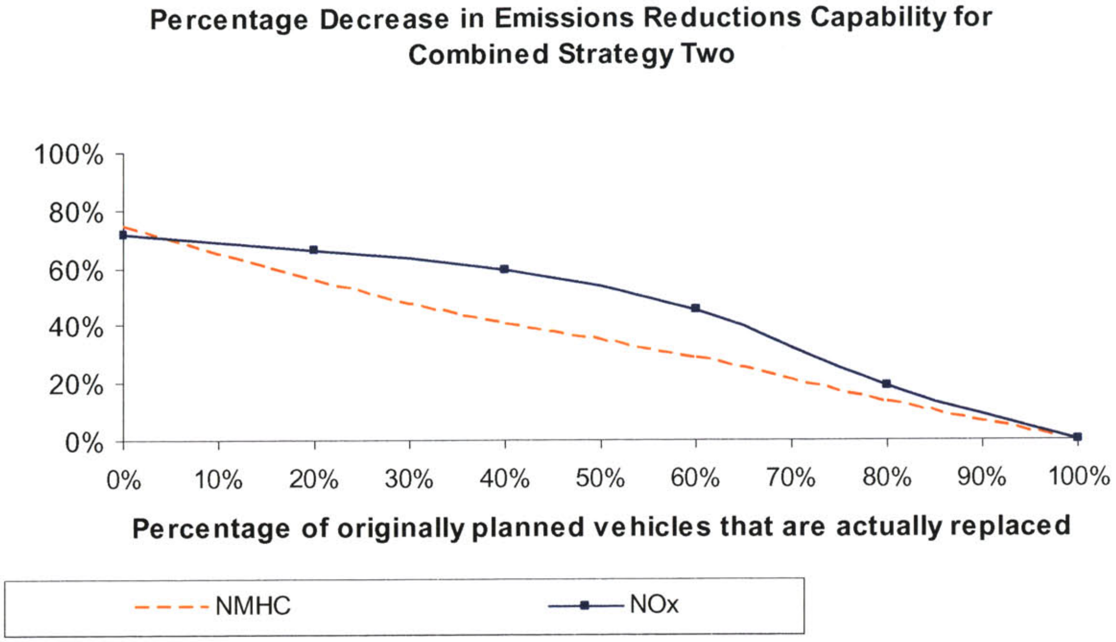
Table 5-14 Percentage Reduction of Combined Vehicle Technology and Fuel Quality Improvement Strategies' Effectiveness in Achieving Emissions Reductions

Combination	**Changes**	**NMHC**			**NO_x**			**PM_{10}**		
		DC	**CC**	**GU**	**DC**	**CC**	**GU**	**DC**	**CC**	**GU**
1	a. More Lenient Schedule **b.** Maximum age 20 years	24%	26%	27%	20%	22%	22%	29%	29%	28%
3	**a.** Maximum age 20 years	20%	20%	21%	30%	30%	30%	50%	50%	-
5	**a.** More Lenient Schedule **b.** Maximum age 20 years	21%	21%	22%	25%	26%	26%	32%	32%	29%

Notes: 🟨 0%-20% reduction 🟦 21%-50% reduction 🟧 51%-100% reduction

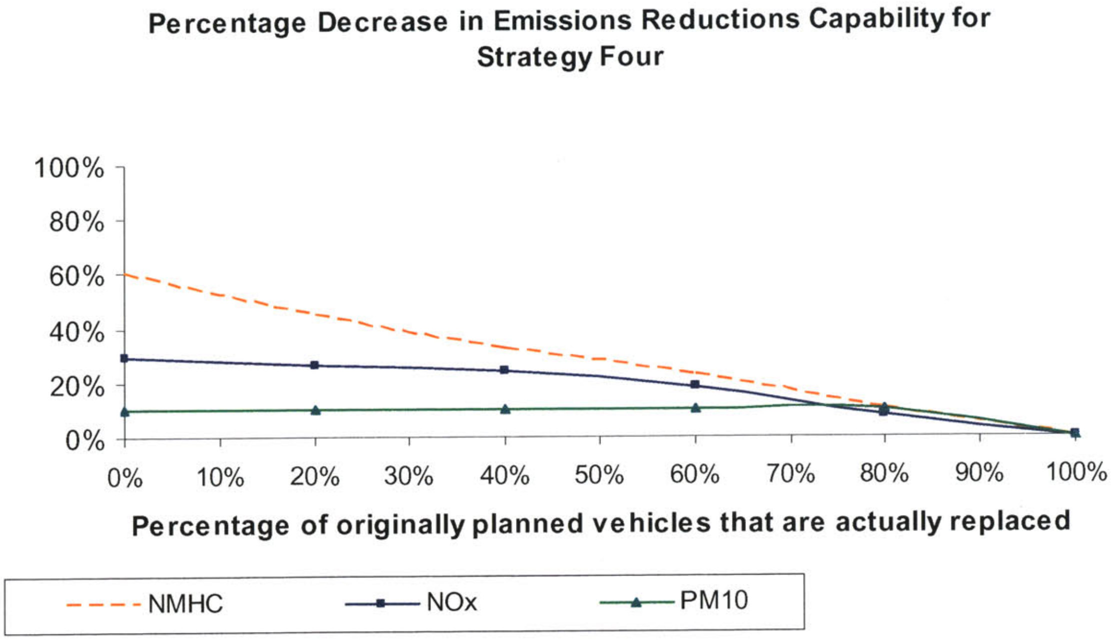
Empty cells mean that there were no emissions reductions for that pollutant before the implementation change

Figure 5-13 Percentage Decrease of Combined Strategy Two's Emissions Reductions Capability



From figure 5-13 we can note that combined strategy two's NMHC and NOx emissions reductions capability could decrease up to approximately 75% and 70%, respectively, with respect to the base case depending on the percentage of originally vehicles that are actually replaced. We have not included PM_{10} emissions because this combined strategy would not achieve considerable emissions reductions for this pollutant even if implemented as planned.

Figure 5-14 Percentage Decrease of Combined Strategy Four's Emissions Reductions Capability



From figure 5-14 we can note that combined strategy four's NMHC and NOX emissions reductions capability could decrease up to 60% and 30%, respectively if not implemented as planned. This combined strategy's capability of achieving PM10 emissions reductions would not decrease significantly (up to a 10%) if not implemented as planned.

Even when these combined strategies seem to be robust in terms of emissions reductions, we should still estimate what their emissions levels in the future would behave in case they are not implemented perfectly. Table 5-15 presents the percentage increase or decrease of year 2025 emission levels with respect to year 2000 levels for all combined strategies and pollutants.

Table 5-15 Combined Vehicle Technology and Fuel Quality Improvement Strategies Performance with Respect to Changes in their Implementation (Percentage Increase/Decrease of Year 2025 Emission Levels with Respect to Year 2000

Combination	**Changes**	**NMHC**			**NO_x**			**PM_{10}**		
		DC	**CC**	**GU**	**DC**	**CC**	**GU**	**DC**	**CC**	**GU**
1	**a**. More Lenient Schedule **b.** Maximum age 20 years	63%	23%	91%	38%	8%	68%	-32%	-41%	-14%
2	**a.** Maximum age 20 years **b.** Replacement of 50% of vehicles originally planned	40%	8%	74%	65%	30%	103%	94%	65%	145%
3	**a.** Maximum age 20 years	-9%	-33%	10%	33%	1%	59%	84%	63%	140%
4	**a**. More Lenient Schedule **b.** Maximum age 20 years **c.** Replacement of 50% of vehicles originally planned	23%	-5%	53%	15%	-8%	47%	-33%	-42%	-14%
5	**a**. More Lenient Schedule **b.** Maximum age 20 years	-27%	-47%	-11%	-17%	-37%	3%	-35%	-43%	-16%

Notes: 1) DC= "Divided City"; CC= "Changing Climates"; 3) GU= "Growth Unbound".

1) For combined strategies two and four we have only included the case where 50% of all vehicles originally planned are actually replaced

From this table we can see that combined strategy five could be considered the most robust with respect to future emissions levels in the presence of imperfect implementation. In fact, this combined strategy would still present a decrease in emission levels in year 2025 compared to 2000 for all future stories and all pollutants, except NO_x under the future story “Growth Unbound”, where we would have a 3% increase.

Combined strategy one would still present a decrease in emission levels for PM_{10} under all three future stories. Combined strategy four would also present a decrease in emission levels for $PM_{10,}$ but not for NMHC and NO_x.
Combined strategy three would no longer achieve a decrease in emission levels for all three future stories for NMHC, while strategy two would practically fail to achieve a decrease in emission levels for all three pollutants and all three future stories.

Our analysis of these five combined strategies so far includes an estimation of their capability of achieving substantial and sustained freight-related emissions reductions, as well as the costs of the MCMA freight fleet if they are implemented. We have also determined their performance with respect to changes in their implementation. Tables 5-16, 5-17 and 5-18 include a summary of each combined strategy's overall performance for all three pollutants analyzed.

Table 5-16 Combined Vehicle Technology and Fuel Quality Improvement Strategies' Performance for NMHC

Combined Strategies	Emissions Reductions with Respect to Base Case	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000	Percentage Increase of Total Costs with Respect to Base Case	Percentage Decrease of Emissions Reductions with Respect to Changes in the Implementation	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000 when considering Implementation Changes
1	7%	17%-83%	7.4%-7.8%	24%-27%	23%-91%
2	35%-39%	(9%)-51%	6.1%-6.6%	Up to 75%	(1%)-74%
3	46%-47%	(46%)-(11%)	7.5%-8.4%	20%-21%	(33%)-10%
4	44%-49%	(30%)-(5%)	11.9%-13.9%	Up to 60%	(14%)-53%
5	53%-54%	(65%)-(40%)	14.8%-16.2%	21%-22%	(47%)-(11%)

Note: figures in parenthesis represent negative value

From table 5-16 we can note that combined strategy five has the best performance with respect to NMHC. This strategy is capable of achieving up to a 54% of freight-related NMHC emissions reductions with respect to the base case, as well as future emission levels up to 64% lower than year 2000 level. Furthermore, if the implementation changes occur, its capability of achieving freight-related NMHC emissions reductions would decrease by approximately 22%, but it would still be able to maintain a decrease in future emissions (between 47% and 11% with respect to year 2000). Strategy three would have the second best performance.

This strategy would also achieve substantial and sustained freight-related NMHC emissions reductions if implemented perfectly. If this is not the case, we can no longer expect it to achieve lower emission levels in the future for all future stories since for the future story "Growth Unbound" it would present a 10% increase with respect to year 2000 emission levels. Combined strategy four overall performance is similar to that of combined strategy two, except that its capability of achieving sustained NMHC emissions reductions is smaller. If implemented perfectly, this strategy would achieve substantial and sustained emissions reductions; however, if this is not the case, its future NMHC emissions level would not be lower than in year 2000 for all three future stories.

Table 5-17 Combined Vehicle Technology and Fuel Quality Improvement Strategies' Performance for NO_x

Combined Strategies	Emissions Reductions with Respect to Base Case	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000	Percentage Increase of Total Costs with Respect to Base Case	Percentage Decrease of Emissions Reductions with Respect to Changes in the Implementation	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000 when considering Implementation Changes
1	24%-25%	(6%)-48%	7.4%-7.8%	20%-22%	8%-68%
2	16%-18%	20%-90%	6.1%-6.6%	Up to 70%	24%-103%
3	22%-23%	(9%)-43%	7.5%-8.4%	30%	1%-59%
4	41%-44%	(33%)-11%	11.9%-13.9%	Up to 30%	(13%)-47%
5	47%-48%	(60%)-(34%)	14.8%-16.2%	30%-31%	(37%)-3%

Note: figures in parenthesis represent negative value

From table 5-17 we can see that combined strategy five would have the best performance for NO_x emissions. This strategy, if implemented perfectly, would be capable of achieving up to a 48% of freight-related NO_x emissions reductions with respect to the base case, as well as future emission levels up to 60% lower than those of year 2000. When considering changes in its implementation, its emissions reduction capability would decrease by approximately 30% and its future emission levels would still be lower than those of year 2000 for all future stories except "Growth Unbound", under which they would rise by approximately 3%. Combined strategy four would be able to achieve substantial freight-related NO_x emissions reductions if implemented perfectly, however they would be sustained under all future stories. Future emissions levels could be up to 11% higher than those of year 2000. When considering changes in its implementation, its emissions reduction capability could decrease up to 30% and its future emission levels could be up to 47% higher than those of year 2000.

Table 5-18 Combined Vehicle Technology and Fuel Quality Improvement Strategies' Performance for PM_{10}

Combined Strategies	Emissions Reductions with Respect to Base Case	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000	Percentage Increase of Total Costs with Respect to Base Case	Percentage Decrease of Emissions Reductions with Respect to Changes in the Implementation	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000 when considering Implementation Changes
1	34%-37%	(77%)-(66%)	7.4%-7.8%	28%-29%	(41%)-(14%)
2	1%-3%	66%-149%	6.1%-6.6%	-	67%-145%
3	1%-2%	67%-150%	7.5%-8.4%	100%	63%-140%
4	36%-40%	(80%)-(70%)	11.9%-13.9%	Up to 10%	(42%)-(14%)
5	36%-40%	(79%)-(69%)	14.8%-16.2%	29%-32%	(43%)-(16%)

Note: figures in parenthesis represent negative values

Combined strategies one, four and five have a similar performance. They would all be capable of achieving substantial (up to 40%) and sustained freight-related PM_{10} (up to 79% lower emission levels compared to 2000) emissions reductions if implemented perfectly. Furthermore, even when considering changes in their implementation, they would still be capable of achieving substantial and sustained emissions reductions.

5.5 Key Assessments and Findings

In this chapter we have analyzed eight different vehicle technology and fuel quality improvement strategies, as well as five different combined strategies. We have estimated their overall performance in terms of their capability of achieving substantial and sustained emissions reductions, the costs of the MCMA freight fleet if they are implemented, as well as their robustness with respect uncertainties posed by the "Future Stories" and to changes in their implementation.

We have seen that when considering the vehicle technology and fuel quality improvement strategies by themselves, these would not be able to achieve both substantial and sustained emissions reductions; however, by constructing combinations of these strategies we could achieve both substantial and sustained emissions reductions under different future stories and when considering imperfect implementation.

Our analysis shows that combined strategy five, which includes setting stricter emissions standards for new heavy-duty diesel vehicles and establishing a maximum age limit of 15 years for heavy-duty diesel and gasoline vehicles and light-duty gasoline vehicles, would yield the best results in terms of substantial and sustained emissions reductions. Even though this combined strategy would also cause the highest cost increase (approximately 15% with respect to the base case), the ratio of emission's reductions for any pollutant divided by its associated cost of the MCMA fleet, would be higher than that of any other combined strategy.

These results must be presented to decision-makers in the MCMA and discuss with them their priorities in terms of emissions reductions for each pollutant. For instance, if they are mostly interested in reducing PM_{10} emissions, they could implement combined strategy one whose performance with respect to this pollutant is among the best. Furthermore, by presenting the results disaggregated by pollutant and future story, as well as by different changes in their implementation, decision-makers can assess their priorities in terms of emissions reductions, as well the level of risk they are willing to take and its implications in terms of a strategy's performance. For example, we have seen that some combined strategies perform well under all future stories except "Growth Unbound". A decision maker may wish to implement one of these combined strategies and by analyzing our results can have an estimate of its performance in case a future similar to the future story "Growth Unbound" unfolds.

CHAPTER 6: FREIGHT FLEET OPERATIONAL AND UTILIZATION IMPROVEMENT STRATEGIES TO IMPROVE AIR QUALITY IN THE MEXICO CITY METROPOLITAN AREA

6.1 Introduction

As mentioned in Chapter Five, there are different freight strategies that can be used to improve air quality in the MCMA. Based on their characteristics, these strategies can be divided into two categories: 1) vehicle technology and fuel quality improvement strategies and 2) fleet operational and utilization improvement strategies. In this chapter we present and analyze three different strategies included in the second category. Their capability of achieving substantial and sustained emissions reductions of key pollutants, NMHC, NO_x and PM_{10} is estimated. Their robustness with respect to the uncertainty posed by the "Future Stories", as well as assumptions made in the modeling process is also analyzed. Furthermore, uncertainty issues related to their implementation and usage are also analyzed and discussed.

This chapter also includes a series of combined strategies that include strategies from both freight categories, vehicle and fuel quality improvement, and fleet operational and utilization improvement strategies. Their performance in terms of substantial and sustained emissions reductions, as well as their robustness with respect to the uncertainty posed by the future stories, the assumptions made in the modeling process and their implementation is also analyzed and discussed.

6.2 Fleet Operational and Utilization Improvement Strategies

Throughout our analysis of the freight transportation system in the MCMA we have noted that freight vehicles' contribution to pollutant emissions is substantial. Even though we have not been able to quantify freight vehicles' contribution to congestion, it seems reasonable to believe that it is also substantial. For example, heavy-duty freight trucks in the MCMA, because of their characteristics (i.e. size and limited maneuverability) can substantially slow down the traffic flow of streets in the city's road network[56]. These contributions to pollutant emissions and congestion are further enhanced by operational inefficiencies of the freight transportation system.

The strategies included in this category have as their main characteristic the improvement of freight operations and utilization in the MCMA to achieve emissions reductions. Such emissions reductions would be attributable to two factors:

1. A more efficient way of using the available number of vehicles which could yield a reduction of freight vehicle-km traveled within the MCMA.

2. A reduction in congestion. Emission rates, measured as grams/mile, increase significantly under the presence of congestion[57]. Since freight transportation is an important contributor to congestion, especially heavy duty trucks, by improving their operations it could be possible not only to lower emission rates for freight vehicles, but also the emission rates of other vehicles, such as private autos and buses, by alleviating congestion.

To craft the strategies in this category we focused on two components of the freight transportation system: 1) the local freight fleet; and 2) the out of region freight fleet. The local freight fleet includes all those vehicles that have both an origin and a destination within the MCMA, while the out of region freight fleet includes all those vehicles that have an origin or a destination outside the MCMA. The out of region freight fleet either picks up or delivers good leaving or entering the MCMA.

6.2.1 Out of Region Freight Fleet Operation Improvement

The out of region freight fleet is composed mostly of heavy-duty diesel and gasoline vehicles[58]. These vehicles enter the MCMA to either deliver or pickup goods leaving or entering the MCMA. Heavy-duty vehicles, especially diesel powered, are designed to be

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[56] The author has personally experienced this in the MCMA for over 24 years.
[57] See figures 2-4 and 2-5 in Chapter 2.
[58] See section 2.3.3 and 2.3.4.

used for long-haul trips on highways; thus they are not well suited to circulate in an urban road network, which causes them to contribute significantly to the poor traffic conditions in the MCMA. These vehicles, as seen in chapter two, also have the highest emission rates for NHMC, NO_x and PM_{10} pollutants. Furthermore, once they enter the MCMA to either deliver or pickup freight, they can spend a considerable amount of time within the city caught in traffic, which increases their vehicle-cycle times. The financial implications of an increase in the vehicle-cycle time may be substantial since it can force companies to increase their vehicle fleets in order to maintain a desired level of service in their distribution systems. Generally, companies want to keep their heavy-duty vehicles circulating in the highways, where they are more efficient, and not within urban areas.

Keeping out of region heavy-duty diesel and gasoline vehicles from circulating within the MCMA could have considerable environmental and financial impacts on the region. However, to estimate such impacts it is necessary to first devise a way to either pick up or delivery the goods these heavy-duty vehicles would normally carry. For instance, these pick ups and deliveries could be carried out by a series of light-duty gasoline trucks. In order to better estimate the environmental and financial impacts we would also have to account for the emissions and costs of these added light-duty gasoline vehicles.

Having this in mind, we have estimated the impact on NMHC, NOx and PM_{10} pollutant emissions if out of region heavy-duty diesel and gasoline vehicles are kept out of the MCMA. In such estimations we have assumed that the goods carried by a heavy-duty diesel or gasoline vehicle would be either delivered or picked up by a certain number of light-duty gasoline vehicles. Such number of vehicles depends on the carrying capacity and capacity utilization of heavy-duty diesel and gasoline vehicles, as well as that of light-duty gasoline vehicles, as shown in table 6-1.

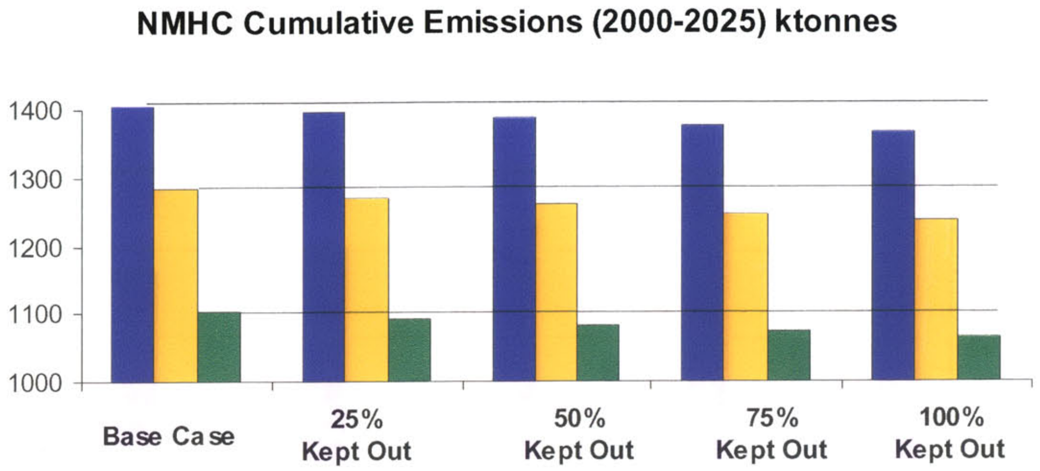
Table 6-1 Average Carrying Capacity and Utilization for Out of Region Heavy-Duty Diesel and Gasoline Vehicles, and Light-Duty Gasoline Vehicles

Vehicle Type	Average Carrying Capacity (tonnes)	Average Capacity Utilization	Actual Carrying (tonnes)	Equivalent Number of light-duty gasoline vehicles
Heavy-duty diesel vehicle	12	60%	7.2	**6**
Heavy-duty gasoline vehicle	8	60%	4.8	**4**
Light-duty gasoline vehicle	3	40%	1.2	**1**

Estimating an equivalent number of light-duty gasoline vehicles using vehicle weight capacity might not yield accurate results since it does not account for volume capacity. For instance, a vehicle might use only 50% of its weight capacity, but 90% of its volume capacity. This is especially true for products with low density (tonnes/m^3). Accounting for volume capacity would probably change the number of light-duty gasoline vehicles needed to deliver or pick up the cargo of a heavy-duty diesel or gasoline vehicle. In our initial estimations of the impact of keeping heavy-duty vehicles from circulating in the MCMA, the vehicle equivalency is based only on weight capacity due to the lack of data available for vehicles' volume capacity utilization; however, later on our analysis we address the impact on emission levels of doing this.

Figures 6-1, 6-2 and 6-3 show the impact on NMHC, NO_x and PM_{10}, respectively, of keeping out of region heavy-duty diesel and gasoline vehicles from circulating in the MCMA and having light-duty gasoline vehicles making the final deliveries or initial pick ups.

Figure 6-1 Impact of Keeping Out of Region Heavy-Duty Diesel and Gasoline Vehicles Out of the MCMA on NHMC Emissions



Emissions Reductions with Respect to Base Case

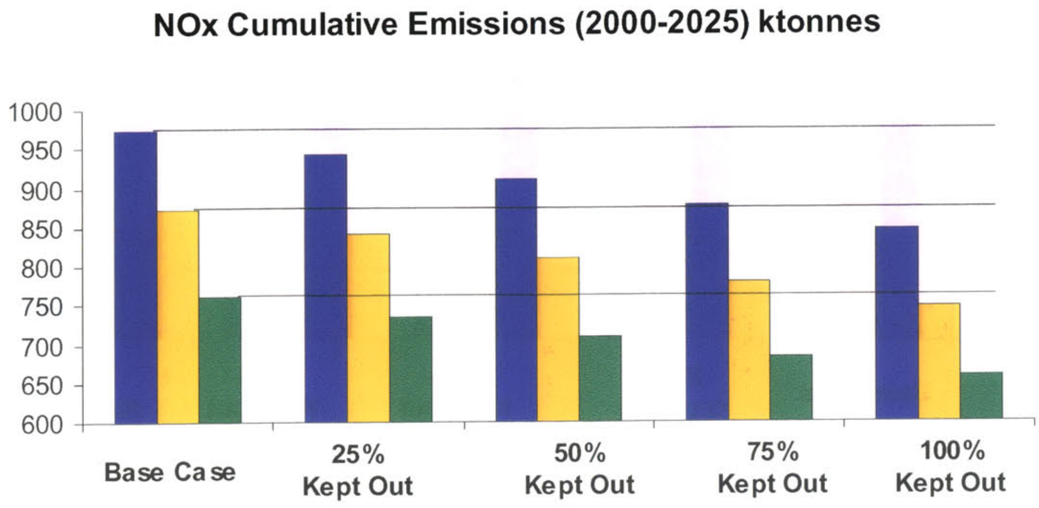
DC	1%	2%	3%	4%
CC	1%	2%	3%	3%
GU	1%	1%	2%	3%

🟨 Divided City 🟩 Changing Climates 🟦 Growth Unbound

Note: DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound"

From this figure we can see than keeping out of region heavy-duty diesel and gasoline vehicles from circulating in the MCMA would not have a considerable impact on freight-related NMHC emissions. In fact, even when keeping all out of region heavy-duty diesel and gasoline from entering the MCMA, NMHC freight emissions reductions would only amount up to a 4% with respect to the base case.

Figure 6-2 Impact of Keeping Heavy-Duty Diesel and Gasoline Vehicles Out of the MCMA on NO_x Emissions



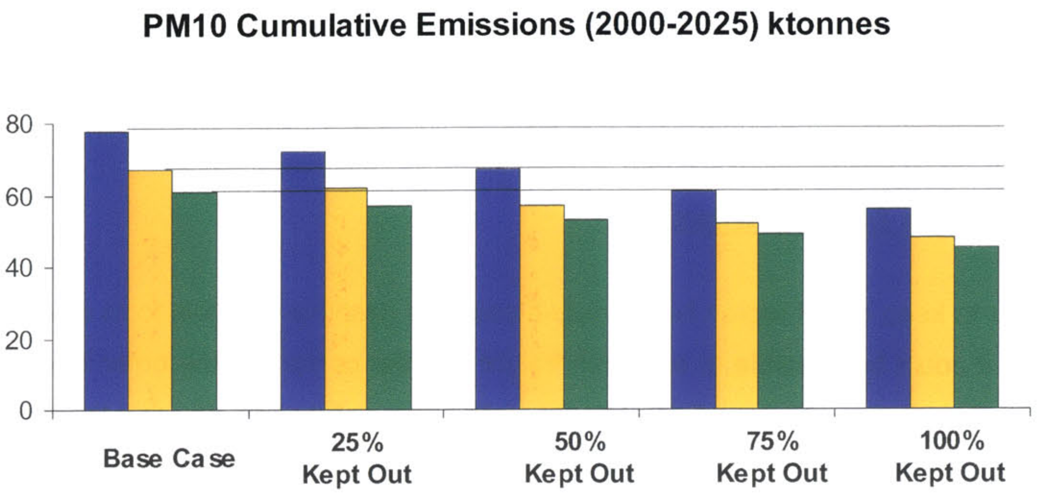
Emissions Reductions with Respect to Base Case

DC	4%	7%	11%	14%
CC	3%	7%	10%	13%
GU	3%	7%	10%	13%

Note: DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound"

From figure 6-2 we can take two readings. First, that the impact on freight NO_x emissions of keeping out of region heavy-duty diesel and gasoline vehicles from circulating in the MCMA could be substantial (up to 14% with respect to the base case). Second, significant emissions reductions will only occur if a considerable amount of out of region heavy-duty vehicles is kept out of the MCMA. If only 25% of all out of region heavy-duty diesel and gasoline vehicles are kept out of the MCMA, NO_x emissions reductions would only amount up to 4%.

Figure 6-3 Impact of Keeping Heavy-Duty Diesel and Gasoline Vehicles Out of the MCMA on PM_{10} Emissions



Emissions Reductions with Respect to Base Case

DC	7%	15%	22%	28%
CC	7%	13%	20%	26%
GU	8%	14%	22%	28%

Note: DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound"

From this figure we can note that the impact of keeping heavy-duty diesel and gasoline vehicles from entering the MCMA would be greatest for PM_{10} emissions. For this particular pollutant, freight-related emissions reductions could amount up to nearly 30% with respect to the base case.

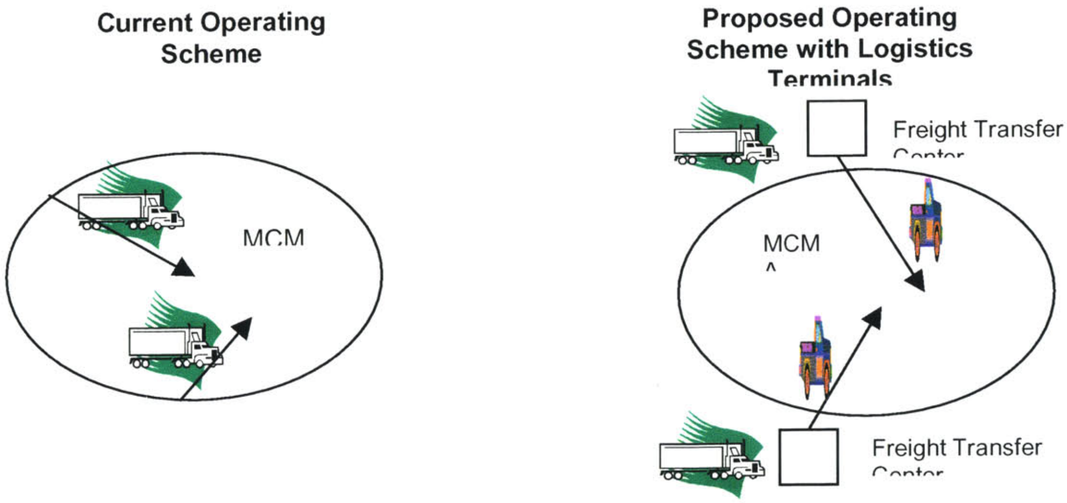
We have seen that the impact of keeping out of region heavy-duty diesel and gasoline vehicles from circulating in the MCMA could be significant for both freight-related NO_x and PM_{10} emissions; however, we still need to develop strategies to keep them out of the MCMA without negatively affecting its economic growth.

Based on our research and information presented in SETRAVI (1996) we will explore two strategies aimed towards keeping out of region heavy-duty diesel vehicles from circulating in the MCMA. The first involves the installation of freight transfer centers in the outer limits of the city, while the second involves increasing the utilization of the railroad for transporting goods entering or leaving the MCMA.

6.2.1.1 Freight Transfer Centers

In order to keep out of region heavy duty-diesel and gasoline vehicles form entering the MCMA it could be possible to establish freight transfer centers in the outer limits of the MCMA that would work as a liaison between the heavy-duty vehicles and the light duty vehicles conducting the final delivery or initial pickups within the city. Figure 6-4 illustrates the overall operating scheme of these transfer centers.

Figure 6-4 Freight Transfer Centers Operating Scheme



Current Operating Scheme

Proposed Operating Scheme with Logistics Terminals

These types of freight transfer centers have been established in different urban areas around the world. Visser et al. (1999) mention that these types of freight transfer centers are currently operating in urban areas in France, Germany, the Netherlands and Japan.

Antun et al. (2000) further mention that they have also been established in Spain (Barcelona) and Canada (Montreal).

The operating scheme, as well as the services these freight transfer centers offer differs between cities. For instance, in Germany and Italy, they are usually composed of a series of transshipment terminals where the incoming heavy-duty vehicles unload their freight which is then loaded to the light-duty vehicles. In Barcelona, freight transfer centers include not only transshipment terminals, but also warehouses where goods are stored. They also offer value added services, such as warehousing and packaging.

Existing freight centers have been developed and operated by both the private and public sector. In France most freight transfer centers have successfully been developed and operated by the private sector. In fact, its two biggest freight transfer centers, Garonor and Rungis, which are located in the Paris region, were developed by private companies. On the other hand, Visser et al. (1999) mention that in Japan, the public sector played an important role in both the development and operation of most of the freight transfer centers established in the Tokyo area.

Even when these freight centers have been developed and operated by the private sector, there should be involvement from the public sector. In Germany, Italy and France, where freight transfer centers have successfully been established, they form an important part of their national policies. The governments of these countries not only encourage their establishment and usage, but also invest public funds in their development and operations.

In the case of the MCMA, we envision logistics transfer centers that should be established in well connected areas located in the outer limits of the city. It is essential that they are easily accessible for both the heavy-duty vehicles, as well as the light-duty vehicles; thus, they should be located on the main highways connecting the MCMA with the rest of the nation. Like the transfer centers developed in Japan, the government should play an important role in both their development and operation. It is not desirable that the government operates these centers by itself, since past experiences in Mexico show that government- owned transportation companies, such as Ferrocarriles

Nacionales de Mexico, rarely provide efficient and reliable services[59]; thus, it is important that the private sector participates as well in both the development and operation of these freight centers. The government could promote the private sector's involvement by offering them fiscal and financial incentives. For instance, the government could absorb the capital costs related to the initial development of these centers (i.e. land acquiring costs, construction costs). Furthermore, it could offer fiscal incentives, in terms of tax reductions to companies using these freight centers.

The developers of these freight centers should aim at attracting large companies operating in the MCMA, such as retail companies (i.e. Wal Mart) to establish their distribution centers in them; However, they should not only focus on these type of companies, but also let for hire companies, such as third party logistics (3PL's) to establish their operations in these centers.

The services offered in these centers should not only include transportation services, but also other logistics related services, such as warehouse management, packaging of finished goods, order fulfillment, cross docking operations and access to advanced information technology services. Offering these services could make them more attractive to potential users.

Even though these freight transfer centers have been intended to solve urban freight transportation problems by improving urban goods traffic, their potential benefits also include the economic growth of the region, through the creation of jobs and the improvement of trade between the region and other regions, as well as contributing to the creation of a sustainable and viable freight transportation system for the MCMA.

The costs associated with the establishment of these freight transfer centers include:

1) *The capital cost of acquiring the light-duty vehicles that will carry out the final deliveries or initial pick ups.* These costs depend on the type of light-duty vehicles that are purchased. We have said that they could be powered by gasoline; however, they could also be powered by natural gas.

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[59] See section 2.4 in Chapter 2

2) *Land acquisition and construction costs*. Land acquisition costs would vary depending on the location where the freight transfer center is established. For instance, land in the northern part of the MCMA (main highway to Queretaro) could be valued higher than in the northeastern part of the MCMA (main highway to Puebla). Construction costs can also vary considerable. For example, the construction cost of a warehouse is different if it will store refrigerated goods, than if it stores grains. Furthermore, the size and number of warehouses will also have an impact on costs.

3) *Technology acquisition costs*. Depending on the services offered by the freight transfer center, these costs could prove to be significant. For instance, a freight transfer center that offers value added processes, such as warehouse management, and packaging of finished goods, would have to purchase computer equipment (i.e. hardware and software) and specialized machinery that could prove to be expensive.

4) *Operating costs*. These costs include labor and administrative costs. Depending on the services offered, the wages of workers could vary. In general, specialized value added services require higher paid workers. Drivers' wages are also included in this cost component.

5) *Transportation costs*. These costs are related to the fuel consumption and maintenance of the light-duty vehicles that will carry out the final deliveries or initial pick ups. However, they also relate to the costs of the heavy-duty diesel vehicles originally carrying the goods to be delivered or picked up. Once a heavy-duty vehicle is kept out of the MCMA, the owner of the vehicle could use it for different purposes. For example, let's assume that a company in Monterrey[60] owns several heavy-duty diesel trucks that it uses to transport its merchandise to the MCMA. Once the freight transfer centers are established outside the MCMA, these trucks will no longer have to circulate within the MCMA; thus their cycle-times will be reduced. The company could then have the option of reducing the number of trucks needed to serve the MCMA. The trucks no longer needed could

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[60] Monterrey is the third largest city in Mexico. The traveling time of a truck between Monterrey and the MCMA is approximately 12 hours.

either be sold or used to serve other customers in different regions of the country. In such a case, there would be an avoided cost since the company would not have to increase its vehicle fleet if it decides to expand.

6) *Inventory related costs.* The inventory costs relate to the holding costs of the products transported into or out of the MCMA. It has been argued by Whiteing et al. (2003) that establishing freight transfer centers would most likely increase these costs since these centers would only add a step in the supply chain; however, it is not clear that they will necessarily increase. For instance, companies that previously did not have access to services such as warehouse management and information technology might actually improve their inventory policies, thus reducing their overall inventory costs.

6.2.1.2 Increase in Railroad Utilization for Transporting Goods Entering/Leaving the MCMA

Establishing freight transfer centers in the outer limits of the MCMA could be used to keep heavy-duty diesel and gasoline vehicles from circulating in the MCMA; however, there is another way that could potentially keep these vehicles from entering the city.

Currently, less than 10% of all freight currently entering the MCMA is transported by the railroad[61]. As mentioned in Chapter 2, one possible reason behind this is the fact that all railroad operations prior to 1997 were carried out by a state owned company called Ferrocarriles Nacionales de Mexico (FNM). The services offered by FNM were not competitive with trucks, their shipments were often late and the cargo damaged. Now days, railroad operations are carried out by private companies whose main objectives include increasing their competitiveness by offering better and more reliable services. If these companies could increase their share of the freight entering or leaving the MCMA, they would indirectly keep out of region heavy-duty vehicles from circulating in the MCMA. Similarly to freight transfer centers, the freight reaching the rail terminal by railroad could be delivered to its final destination by light-duty vehicles. Likewise, freight

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[61] INEGI (2000)

leaving the MCMA could be transported to the rail terminal using light-duty vehicles and later on loaded onto the railroad.

In order to have companies shift transportation modes from trucks to railroad it is necessary to offer them incentives. It is not only necessary to have railroad companies offering good and reliable services for transporting goods from other regions into their rail terminals in the MCMA, but other services are also required. For instance, it could be possible to transform the rail terminals currently operating in the MCMA into intermodal terminals. These terminals are mostly aimed towards containerized freight transportation. Therefore, for them to operate effectively in the MCMA, two things are needed:

1) They must have the necessary infrastructure and human capital to perform efficient transfers between the railroad and road vehicles.
2) Their clients must be offered the possibility of loading their freight into containers within the terminal.

Furthermore, just as in the case of freight transfer center, value added services, such as warehousing and warehouse management, packaging of finished goods, and product tracking through geographical information systems (GPS) should be offered to increase their attractiveness. By offering attractive and competitive services, intermodal terminals could efficiently work as a liaison between incoming freight transported by railroad and delivered to its final destination by a series of light-duty vehicles and vice versa.

Visser et al. (1999) document that switching traffic from roads to rail has been attempted and is currently being done by the German government through the installation of what they call Guterverkehrszentrums[62] (GVZ's or Cargo Transfer Centers) in different locations in the country. Some of these GVZ's have been installed in railroad terminals located in the outer limits of different cities. Currently, there are 30 GVZ locations situated in cities such as Bremen, Augsburg, Dortmund, Hannover, Leipzig, Munchen, Neurenberg, Rostock and Trier. Some of these GVZ's not only include the necessary facilities to load and unload freight from trains to trucks and vice versa, but also offer other services, such as warehouse management.

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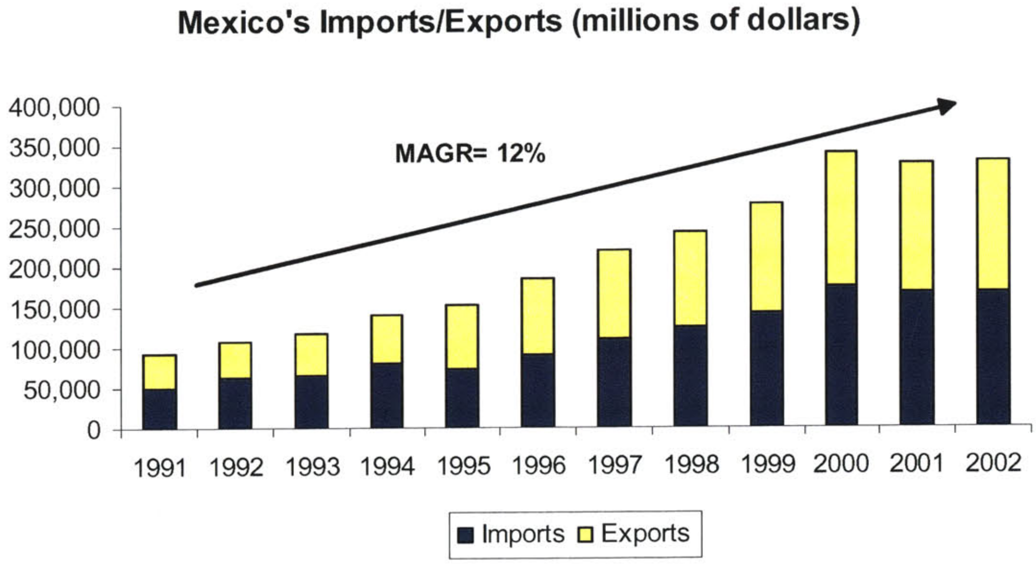
[62] GVZ can be viewed as intermodal terminals working as a liaison between road vehicles and railroads.

We believe that current times offer a window of opportunity for increasing railroad utilization for freight entering or leaving the MCMA. The commercial activity between Mexico and other nations has increased substantially in recent years. Mexican exports and imports experienced an annual growth of approximately 12% between 1991 and 2002, as seen in figure 6-5.

Figure 6-5 Imports and Exports of Mexico

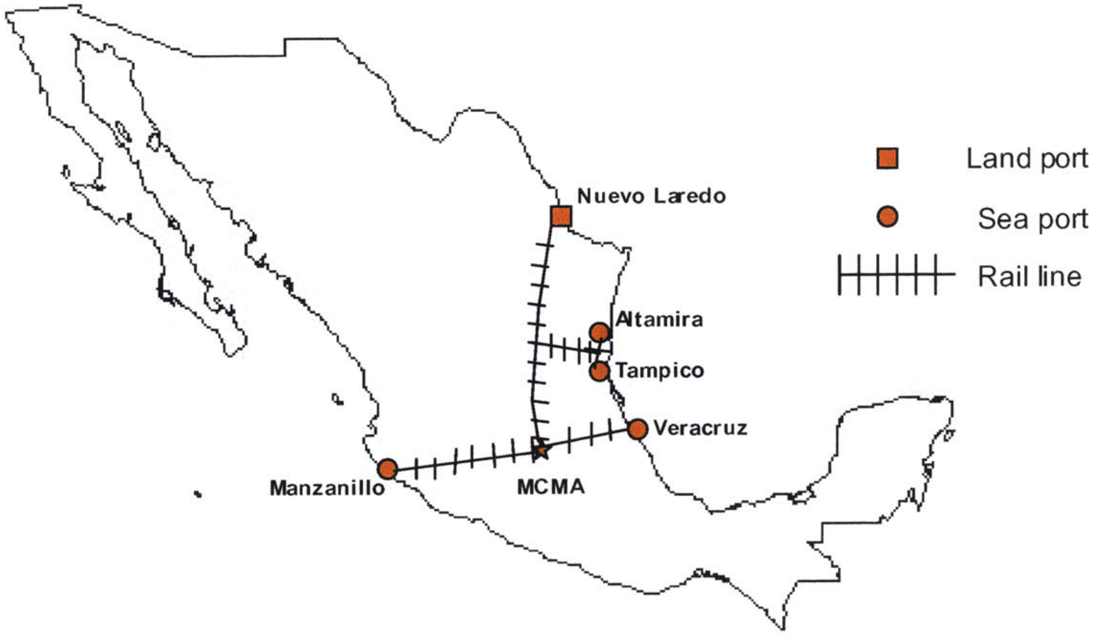


Source: Instituto Nacional de Geografía y Estadística
Note: 1) MAGR= mean annual growth rate; 2) includes all exports and imports of Mexico.

In 1994 Mexico, the United States and Canada signed the North American Free Trade Agreement (NAFTA). Later on in 1998, a free trade agreement was also signed between Mexico and the European Union. Increased trade with both of these regions is one of the drivers of the overall increase in exports and imports.

Most of the imports and exports enter and leave the country through its northern land border (Nuevo Laredo primarily) and its ports (Veracruz, Altamira, Tampico and Manzanillo primarily).

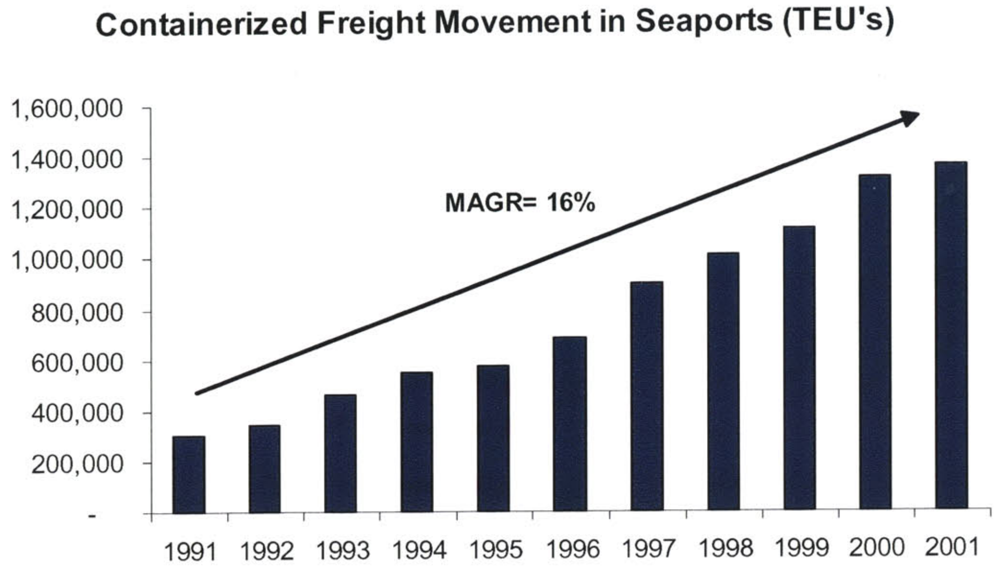
Figure 6-6 Mexico's main sea and land ports



All of the seaports shown in this figure, as well as Nuevo Laredo are connected to the MCMA through railroad lines. The railroad infrastructure of many of these seaports is being upgraded. Furthermore, some of the rail lines connecting them to the MCMA are also being improved. For instance, the port of Manzanillo's rail infrastructure, as well as the rail line connecting the port to the MCMA is being upgraded in order to be able to use double-stack railroads for transporting containerized freight; thus railroads using this port will be offer better transportation services, which in turn could increase their competitiveness with trucks.

Containerized freight moving through Mexican seaports has also increased substantially in the past years, growing at a mean annual growth rate of 16% between 1991 and 2001.

Figure 6-7 Containerized Freight Movement in Mexican Seaports



Source: Secretaria de Comunicaciones y Transportes (www.sct.gob.mx)
Note: 1) MAGR= mean annual growth rate; 2) TEU= container 20 feet long, 8 feet wide and 8.5 feet tall.

As mentioned earlier, intermodal terminals best handle containerized freight. Thus, this substantial increase in containerized freight in Mexican seaports could point towards the installation of intermodal terminals in different regions of the country, including the MCMA.

If we focus on the northern land port, Nuevo Laredo, we can note that railroad's competitiveness with trucks might also keep increasing in the future. As mentioned in Chapter Two, when the privatization of Ferrocarriles Nacionales de Mexico (FNM) took place, three different companies were formed, Ferrocarriles Mexicanos (FERROMEX), Transporte Ferroviaria Mexicana (TFM) and Ferrocarriles del Sureste. These companies are joint ventures between Mexican investors and American railroad companies. For instance, 49% of TFM shares are owned by Kansas Railroad Company. Therefore, these newly formed railroad companies have the capability of transporting goods from the United States into Mexico by railroad without having to perform any transfers with other modes of transportation or other companies. In other words, a freight container loaded in Louisiana can reach the MCMA by railroad through one single operation, which could greatly increase the level of service offered by the railroad company.

Based on these facts, it seems that railroads could increase their competitiveness with trucks for import/export freight destined or leaving the MCMA. This in turn presents a great opportunity to further increase their competitiveness by not only offering these transportation services, but also transforming their rail terminals into intermodal terminals by installing the necessary infrastructure to provide efficient transfers of freight between railroads and road vehicles. Furthermore, they should be capable of loading companies' freight into containers within the terminal.

Another example of how they could make railroads more attractive for imports/exports of companies in the MCMA arises from analyzing potential fiscal incentives that could be offered to them. Even under NAFTA and the Free Trade Agreement with the European Union, there are still a considerable amount of goods that must pay import/export taxes when entering the Mexican territory (i.e. they cross the border or arrive at the port). To make railroads more attractive for companies to transport their imports/exports, the government could establish a program by which the goods transported have a special fiscal treatment. For instance, the railroad company could construct or use existing warehouses to store importing goods in their terminals in the MCMA. Companies using the railroad to transport their imports could store their goods in such warehouses and be given the advantage of not having to pay import taxes until such goods leave the warehouse. This way, the company can avoid paying such taxes when the goods enter the country; thus giving it a considerable financial advantage.

The costs associated with increasing the railroad's utilization for transporting goods entering and leaving the MCMA are similar to those of the freight transfer centers. They would include:

1) *The capital cost of acquiring the light-duty vehicles that will carry out the final deliveries or initial pick ups.* These costs depend on the type of light-duty vehicles that are purchased. We have said that they could be powered by gasoline; however, they could also be powered by natural gas.

2) *Land acquisition and construction costs.* Land acquisition and construction of extra facilities might not be necessary in the case of the railroad since some rail terminals could use their own existing facilities to provide the services described above. However, in some cases it might be necessary to acquire additional land space, as well as to build specialized warehouses or other facilities if they are not currently available.

3) *Technology and equipment acquisition costs.* These costs would include the necessary equipment to transform railroad terminals into intermodal terminals, i.e. efficient load/unloading equipment of freight from vehicles to railroads and vice-versa. Furthermore, these costs would vary depending on the services offered by the intermodal terminal. For instance, if it will offer warehouse management services, as well as container tracking services through global position systems (GPS), it will be necessary to purchase additional technological equipment.

4) *Operating costs.* These costs include labor and administrative costs. Similarly to the transfer centers, these costs would depend on the services offered. If highly specialized value added processes are offered then more highly paid workers will be needed.

5) *Transportation costs.* These costs are related to the fuel consumption and maintenance of the light-duty vehicles that will carry out the final deliveries or initial pick ups.

6) *Inventory related costs and financial costs.* The inventory costs relate to the holding costs of the products transported into or out of the MCMA. It is not clear whether these costs would increase or decrease if freight using trucks switches to the railroad. Following the argument presented by Whiteing et al. (2003) it could be possible that these costs increase since switching to the railroad could represent an additional step in the supply chain. However, as argued earlier, these costs could also decrease if services such as warehouse and inventory management help companies improve their inventory policies.

6.2.1.3 Analysis of Logistics Transfer Centers and Increase of Railroad Utilization for Goods Entering/Leaving the MCMA

Having specified both strategies to keep heavy-duty diesel and gasoline vehicles from circulating in the MCMA we can analyze their potential in terms of emissions reductions as well as to estimate the costs of the MCMA freight fleet in case they are implemented.

With the data available it is not feasible to accurately estimate the amount of out of region heavy-duty vehicles that could use these freight transfer centers. High value, time sensitive freight could be considered as potential freight to use these centers since it is most sensitive to level of service improvements[63]; however, low value freight, not so sensitive to time requirements, could also use them.

Similarly to the freight transfer centers, accurately estimating with the data available the amount of goods entering/leaving the MCMA that would use the railroad as a means of transportation instead of trucks is not feasible. However, when estimating this amount, the characteristics of the railroad should be taken into consideration. For instance, not all regions in the country have access to the railroad; thus, even if the incentives to change from trucks to the railroad are substantial, this would not be possible for the freight generated in these regions. Furthermore, the railroad is usually more competitive with trucks when the distance traveled is considerably large. If the distance from where freight is generated to the MCMA is relatively small (i.e. less than 250 miles) the incentive to switch from trucks to the railroad would have to be substantially large for this to occur.

From figures 6-1, 6-2 and 6-3, presented earlier, we can see what would be the impact on NMHC, NO_x and PM_{10} emissions of keeping heavy-duty vehicles from circulating in the MCMA by using freight transfer centers or increasing the railroad's utilization for transporting goods entering or leaving the MCMA.

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[63] We are assuming that establishing and using freight transfer centers would improve overall level of service provided by its users to their customers.

Our analysis up to this point has assumed that the number of light-duty vehicles needed to deliver or pickup the freight previously carried by a heavy-duty vehicle depended on the carrying capacity and capacity utilization of the heavy-duty and light-duty vehicles. Furthermore, it also assumed that the distance traveled by the light-duty vehicles would be the same than that of the heavy-duty vehicle. For example, a heavy-duty diesel truck traveling 10 kilometers in the MCMA to make a delivery would be replaced by 6 light duty gasoline trucks each traveling 10 kilometers; thus the total number of vehicle-km would be 60.

Since these assumptions might prove not to be precise, they could cause our estimates to be inaccurate. We will revise these assumptions to better understand their implications on our analysis. The actual number of vehicle-km needed to replace a heavy-duty diesel or gasoline vehicle could be higher or lower than the one calculated using the above assumptions for several reasons. We believe it could be lower for three different reasons:

1) *Capacity utilization of the light-duty vehicles increases*. If the light-duty vehicles increase the capacity utilization assumed (40%) the number of vehicles needed to carry out the deliveries or pick ups would be lower; thus, the total number of vehicle-km would also be lower than our previous estimate.

2) *Freight Consolidation*. Light-duty vehicles could consolidate freight of different heavy-duty vehicles when carrying out their deliveries or pickups. By doing this they could increase their capacity utilization, which in turn would produce a lower amount of vehicle-km than our previous estimate. It is worth mentioning that this might not always be possible since it would require collaboration between the different owners of the goods carried. Furthermore, even if the deliveries are carried out by for hire companies (i.e. third party logistics companies) the owners of the goods carried would have to agree to share the available room in the vehicle. Therefore, collaboration would also be needed between companies owning the goods carried.

3) Recalling that the estimate of vehicles' capacity utilization was based on vehicles' weight capacity, it could be possible that accounting for volume capacity the real number of vehicle-km was lower than our original estimate.

The real number of vehicle-km might also be higher than our previous estimate for two main reasons:

1) *Capacity utilization of the light-duty vehicles decreases.* If the average capacity utilization of the light-duty vehicles used is lower than what we assumed (40%), the number of vehicles needed to carry out the deliveries or pick ups would be higher; thus the actual number of vehicle-km would be higher than our estimate. Since the freight centers and the rail terminals would offer services such as warehouse management, it could be possible that the owner of the freight changes its ordering patterns. For instance, it might ask for more frequent deliveries with fewer goods in each one.

2) Once again, our estimate of vehicle's capacity utilization did not include their volume capacity. Thus, it could be possible that when accounting for volume capacity, the real number of vehicle-km was higher than our original estimate.

Finally, in the case of the freight transfer centers, the distance traveled by the light-duty vehicles performing the deliveries and pick ups will depend on the number of freight transfer centers installed. If only one freight transfer center is installed, the distance traveled by them would certainly be higher than if two or more centers are installed.

With the data available it is not possible to determine which of the described possibilities will occur in the future. For instance, we are unable to estimate what the capacity utilization of the light-duty vehicles delivering and picking up freight will be if either the freight centers are installed. However, we should still determine what would be the impact on emissions reductions if our estimate of the equivalent vehicle-km of light-duty vehicles needed to carry out the delivery or pickup of a heavy-duty vehicle was either underestimated or overestimated.

Having this in mind we have estimated the emissions reductions for the case where the real vehicle-km of the light-duty vehicles are 50% and 100% higher than our original estimate, as well as if they were 50% lower than our original estimate. Table 6-2 shows the results for all three pollutants and future stories.

Table 6-2 Emissions Increment/Reduction for Different Levels of Vehicle-km (ktonnes)

Cases	NMHC			NO_x			PM_{10}		
	DC	CC	GU	DC	CC	GU	DC	CC	GU
Base Case	1,283	1,103	1,409	874	760	975	67	61	78
With our original estimate of veh-km	1,260 (-2%)	1,084 (-2%)	1,388 (-1%)	811 (-7%)	710 (-7%)	911 (-7%)	57 (-15%)	53 (-13%)	67 (-14%)
Assuming a 50% decrease of veh-km with respect to original estimate	1,244 (-3%)	1,072 (-3%)	1,370 (-3%)	801 (-8%)	702 (-8%)	899 (-8%)	57 (-15%)	53 (-13%)	67 (-14%)
Assuming a 50% increase of veh-km with respect to original estimate	1,276 (-1%)	1,096 (-1%)	1,406 (0%)	821 (-6%)	718 (-6%)	923 (-5%)	58 (-13%)	53 (-13%)	68 (-13%)
Assuming a 100% increase of veh-km with respect to original estimate	1,291 (1%)	1,108 (0%)	1,425 (1%)	831 (-5%)	726 (-4%)	935 (-4%)	59 (-12%)	54 (-10%)	69 (-12%)

Notes: 1) Assuming 50% of all out of region heavy-duty vehicles are kept out of the MCMA either by using the Logistics Transfer Centers or switching its cargo to the railroad.
2) DC= Divided City; CC= Changing Climate; GU= Growth Unbound
3) Negative figures represent a reduction in emissions with respect to the Base Case

From this table we can make several observations. First, if the real vehicle-km traveled by the light-duty gasoline vehicles were 100% greater than our estimate, freight-related emissions reductions for PM_{10} would not change significantly. In fact, they would only change by approximately two percentage points. Second, freight-related NO_x emissions reductions would be lower than previously estimated, but not substantially. Third, freight-related NMHC emissions would actually increase instead of decrease; however, the increase would not be significant (approximately 1%). Fourth, if the real vehicle-km traveled by the light-duty gasoline vehicles were 50% smaller than our estimate, emissions reductions for all pollutants would remain practically the same as previously estimated. Therefore, any conclusion we reach later on in our analysis with respect to NHMC, NO_x and PM_{10} emissions will not be seriously undermined by our assumption regarding the equivalent number of vehicle-km needed to replace the delivery or pick up of a heavy-duty vehicle with light-duty vehicles.

Our analysis shows that keeping out of region heavy-duty vehicles from circulating in the MCMA would have benefits in terms of NHMC, NO_x and PM_{10} emissions; however, by looking at other pollutants this might not be the case. In fact, if we analyze the impact on freight-related CO_2 emissions, we can see that they could actually increase. Table 6-3 shows freight-related CO_2 emissions in the case where 50% of all out of region heavy-duty vehicles are kept out of the MCMA and deliveries or pick ups are carried out by light-duty gasoline vehicles.

Table 6-3 CO_2 Emissions Increment/Reduction for Different Levels of Vehicle-km (ktonnes)

Cases	CO_2		
	DC	CC	GU
Base Case (ktonnes)	136,130	125,235	158,507
With our original estimate of veh-km	136,300 (0.1%)	126,685 (1%)	159,843 (1%)
Assuming a 50% decrease of veh-km with respect to original case	130,462 (-4%)	121,177 (-3%)	152,682 (-4%)
Assuming a 50% increase of veh-km with respect to original case	142,138 (4%)	132,193 (6%)	167,004 (5%)
Assuming a 100% increase of veh-km with respect to original case	147,977 (9%)	137,701 (10%)	174,165 (10%)

Notes: 1) Assuming 50% of all out of region heavy-duty vehicles are kept out of the MCMA either by using the Logistics Transfer Centers or switching its cargo to the railroad. 2) DC= Divided City; CC= Changing Climate; GU= Growth Unbound 3) Negative figures represent a reduction in emissions with respect to the Base Case

From this table we can note that freight-related CO_2 emissions could decrease up to 4% if the real vehicle-km were 50% lower than our estimate, but increase up to 10% if the real vehicle-km were 100% higher than our estimate. Even though a 10% increase in CO_2 is significant[64], it is worth mentioning that our main goal is to reduce NHMC, NO_x and PM_{10} emissions.

As mentioned earlier, the costs of establishing freight transfer centers or increasing the railroad utilization for goods entering or leaving the MCMA can vary considerably depending on the characteristics of the services offered. Such services in turn depend on the potential freight that could either use the transfer centers or switch from trucks to the railroad. In order to better estimate these costs it would be necessary to carry out a detailed study that would not only determine the potential freight in the MCMA that could use these centers or be switched from trucks to railroad, but also answer questions such

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[64] The MCMA's Emissions Inventory does not include CO_2 emissions disaggregated by sources.

as, what are the requirements of the owners of such freight? What would it take in terms of facilities to attract customers with big distribution systems such as retailers? What type of value added services should be offered to each type of customer?
These are all important questions that must be answered in detail when deciding to either establish a freight center or attract freight to switch from trucks to the railroad; however, currently the information to answer these types of questions is not available in the MCMA.

Estimating the costs of either establishing freight transfer centers or increasing the railroad utilization for goods entering or leaving the MCMA with the level of information available at this point could prove to have a considerable amount of error in them. However, it is still desirable to have an estimate of such costs. In an effort to do this, we decided to estimate what would be the costs of acquiring the light-duty vehicles making the pickups and deliveries within the MCMA. By doing this, our cost estimates could be viewed as a lower bound on the overall costs involved in keeping heavy-duty vehicles from circulating in the MCMA and using light-duty gasoline vehicles to make the deliveries and pick ups within the MCMA. Such costs are shown in table 6-4.

Table 6-4 Total Costs of the MCMA Freight Fleet if Heavy-Duty Vehicles are Kept from Circulating within the MCMA and Light-Duty Gasoline Vehicles Carry out Final Deliveries and Initial Pick Ups.

Strategy	**Present Value of Total Costs of the MCMA Freight Fleet (2000-2025) in BYBMXP[1/]**		
	Divided City	**Changing Climates**	**Growth Unbound**
Base Case	749	925	1,356
Assuming 25% are Kept Out	761 (1.6%)	939 (1.6%)	1,378 (1.7%)
Assuming 50% are Kept Out	772 (3.1%)	954 (3.1%)	1,401 (3.3%)
Assuming 75% are Kept Out	783 (4.6%)	968 (4.7%)	1,424 (5.0%)
Assuming 100% are Kept Out	795 (6.2%)	982 (6.2%)	1,445 (6.6%)

1/ Year 2000 Billion Mexican Pesos. The discount rates are: "Divided City" = 13%; "Changing Climates" = 10%; "Growth Unbound" = 8%.They represent a social discount rate common to all future stories plus the inflation under each future story.

Notes: 1) figures in parenthesis represent the percent increase in total costs with respect to the Base Case.

From this table we can see that keeping heavy-duty vehicles from entering the MCMA could raise costs from 1.6% to 6.6% from the base case depending on the number of vehicles kept out.

Similarly to the strategies presented in Chapter Five, it is important to determine who will bear these costs increments. We have discussed the possibility of having joint public and private ventures when establishing freight transfer centers. Likewise, the public sector could also be involved in the development of intermodal terminals for railroads. Therefore, the costs of implementing either one of these strategies could be paid by the private or public sector solely or in conjunction. In fact, the government could provide the initial funds needed to develop the freight transfer centers or construct the necessary facilities to transform railroad terminals into intermodal terminals and have the private sector bear the costs of purchasing the light-duty vehicles needed to make deliveries and pick ups within the MCMA. Such vehicles could be purchased with low interest loans provided by the government. The use of public funds to implement these strategies can be justified because they would improve the freight transportation system in the MCMA.

In fact, they would help the MCMA have a viable freight transportation system, which is in the city's best interest. Furthermore, these strategies would have other economical benefits associated with them, i.e. economic growth of the region, through the creation of jobs and the improvement of trade between the region and other regions

6.2.2 Local Freight Fleet Operational Improvements

As seen in Chapter Two, the local freight fleet can be divided into the for hire fleet and the private fleet. The for hire fleet is composed of companies that offer transportation services to other companies. The private fleet is composed of privately owned vehicles used by companies to fulfill their own freight transportation requirements. Most of the local freight fleet is composed of light-duty and heavy-duty gasoline vehicles.

We do not have detailed data regarding the operations of both the public and local fleet; however, it has been estimated that approximately 30% of the total amount of trips they make are empty trips[65]. Even though empty trips may be inevitable when operating freight vehicles, having one third of all trips as empty trips seems to be indicative of operating inefficiencies.

It is important to understand what the potential reasons behind these operating inefficiencies are. Currently, many companies in the MCMA rely on their own freight vehicle fleets to distribute their products[66]. Most of these companies are either small or medium in size, which heavily restricts the financial resources they can allocate towards improving their fleet operations. Furthermore, most companies do not have as one of their objectives the reduction of empty trips per se. Even if it is clear that by reducing empty trips they could reduce costs, this does not guarantee their concern in reducing empty trips. Based on these facts, it seems reasonable to assume that private companies will not be able to significantly reduce the number of empty trips under their current operating schemes.

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[65] Desarrollo de Políticas para el Mejoramiento del Ambiente relacionadas con el Transporte de Carga en la Zona Metropolitana del Valle de México. Secretaria de Transporte y Vialidad, 1996.

[66] The local private freight fleet is the biggest component of the freight transportation system in the MCMA with approximately 345,000 vehicles, as mentioned in section 2.3.2 of Chapter 2.

The local for hire freight fleet, whose business is the provision of transportation services, has historically been unable to offer competitive transportation services[67]. The reason behind this can be evident after analyzing this freight fleet component's characteristics. As mentioned in Chapter Two, the fleet is very old, with an average age of 16 years. It is mostly composed of single truck owners commonly called man-truck. The financial resources needed to improve both their fleet and the services they offer are quite limited. Furthermore, most of the companies and individuals that own these freight vehicles are not organized into any type of association that represents their interests and concerns. The fact that this sector has not been able to provide competitive and reliable services is presumably one of the reasons why the many private companies have their own freight vehicle fleets.

Having this in mind, and based on SETRAVI (1996) we will explore a strategy aimed towards reducing the amount of freight vehicles' empty trips, as well as improving the services offered by public companies (for hire) offering transportation services. Such strategy relates to the creation of "Logistics Companies".

6.2.2.1 Logistics Companies

Competitive forces are constantly forcing companies to offer their customers high levels of services. For instance, the adoption of manufacturing practices, such as "Just in Time (JIT)" call for the on-time delivery of products to be incorporated in the production process. If the supplier of products does not meet the level of service requirements posed by on-time deliveries, the whole production system of the manufacturer could be disrupted, causing the loss of substantial amounts of money. This situation is not exclusive to manufacturing firms; for example, retailers demand product availability in order to keep their product shelves full and be able to offer customers a variety of different products. They demand high levels of product availability, but rarely keep product inventory at their facilities, which often translates into more frequent deliveries with less product in each one of them by their suppliers.

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[67] Desarrollo de Políticas para el Mejoramiento del Ambiente relacionadas con el Transporte de Carga en la Zona Metropolitana del Valle de México. Secretaria de Transporte y Vialidad, 1996.

To be able to keep up with these high levels of service requirements and keep costs at reasonable levels, companies must rely on efficient transportation services. As mentioned earlier, their transportation requirements can be fulfilled either by hiring a public transportation company or acquiring and operating their own vehicle fleet. In the MCMA, the acquisition and operation of private fleets has been the dominant approach followed by private companies. However, private companies do not always manage their fleets as efficiently as they could either because they do not have the financial resources or human capital, or simply because, as mentioned earlier, it is not one of their priorities.

It is our belief that in the future, the level of service requirements for freight transportation could increase, thus forcing private companies to either purchase additional vehicles for their distribution systems or manage their fleets more efficiently. On top of this, considering the levels of congestion in the MCMA, providing on-time deliveries will be harder to achieve in the future as trip times not only increase, but also present greater variations. It would be beneficial for the MCMA to create companies that are able to offer efficient and reliable transportation services so that they could fulfill the transportation requirements needed to maintain the high levels of services demanded.

The strategy we present calls for the creation of “Logistics Companies”. We have given this label based on the type of services these companies should provide. First of all, the transportation services they provide should be efficient and reliable. Thus, they would have to use advanced technology to best allocate their vehicles (i.e. dynamic vehicle routing software). However, in order to be attractive to their customers, they should also offer other services. We have mentioned that the need of private companies to offer high levels of service while keeping costs down. Both of these requirements are not only dependent upon transportation, but also on inventory; thus, the logistics companies should also offer services related to inventory management. Furthermore, other value added services, such as product tracking and warehouse management could also be offered to increase their attractiveness to potential customers.

Some of the existing resources available from the local public freight fleet could be used when creating these “Logistics Companies”. It could be possible to group its members and provide the financial and capital requirements needed to form such companies. By creating these companies, the MCMA could benefit economically by having a more efficient local freight transportation system, as well as improving public for hire freight fleet. Furthermore, it could also provide benefits from an environmental perspective for three main reasons:

1) *Vehicle Fleet Renewal.* In order to offer high levels of service, the vehicles these companies use must be in good condition. Since the local public freight fleet is very old (approximately 16 years old) many of these vehicles will have to be replaced with newer ones.

2) *Reduction of Empty Trips.* These new companies' profitability depends on their ability to maximize the utilization of their vehicles. Therefore, it is in their best interest to minimize the number of empty trips their vehicles perform.

3) *Smaller Fleet Size.* By increasing the efficiency of their operations it could be possible to increase the average capacity utilization of their vehicles, which in turn could translate in needing fewer vehicles to offer the level of service requirements needed. For instance, these companies could consolidate freight of one or several private companies on a single vehicle instead of using two vehicles to make the deliveries. It is worth mentioning that it would not always be possible to carry out this task, especially if it involves consolidating freight from different companies since they might not be willing to share the same vehicle, even if there is room available.

The costs associated with the creation of these "Logistics Companies" would include:

1. *Fleet renewal and new vehicle acquisition costs.* As mentioned earlier, offering a high level of service requires the availability of well operating vehicles. Therefore, it would be necessary to renew the local public fleet of the MCMA. Furthermore, it could be possible to have to purchase additional vehicles depending on the number of customers being served by the logistics companies. On the other hand, private companies that hire these logistics companies could no longer need all their vehicles. Therefore, they would have the option of selling such vehicles or utilizing them for a different task, both of which would benefit them financially.

2. *Land acquisition and construction costs.* These companies would have to establish their facilities in one or several locations in the MCMA. Thus, they would have to purchase undeveloped land and construct their facilities, or purchase previously developed facilities. These costs could vary significantly depending on the location within the MCMA, as well as the facilities to be constructed.

3. *Technology acquisition costs.* Depending on the services offered by these companies these costs could also vary considerably. For instance, in order to minimize empty trips, these companies would have to employ advanced technology in terms of vehicle-routing solutions. If they offer, as recommended, product tracking systems, they should also purchase Global Positioning System (GPS) devices.

4. *Operating costs.* These costs relate to labor and administrative costs. Labor costs include the drivers of the vehicles, as well as the men operating the facilities (i.e. warehouses). Furthermore, it includes the men in charge of coordinating and implementing the technological software needed to efficiently provide a high level of service (i.e. implementing dynamic vehicle-routing software). Administrative costs include wages of secretaries and other staff needed for the companies to properly function.

5. *Transportation costs.* These costs include the fuel consumption and maintenance of the vehicles used by these logistics companies.

6. *Inventory related costs.* These costs are related to the inventory holding cost of the goods managed by these logistics companies. With the creation of these logistics companies, private companies that outsource their inventories to these companies could decrease their inventory costs if better and more efficient inventory policies are adopted. In principle these logistics companies would be capable of improving inventory policies by using advanced information systems, as well as employing experienced personnel.

In an effort to quantify the environmental impact of these logistics companies we have estimated the amount of emissions reductions of NMHC, NO_x and PM_{10} that could potentially be achieved if they are created. To estimate such emissions reductions we focused on two key variables, the number of customers that these logistics companies would have, as well as the reduction of empty trips that they could achieve. The number of customers is better represented by the number of vehicles of the local private fleet that would no longer be used because of the hiring of these logistics companies. For instance, a private company owning 50 vehicles might decide to hire a logistics company to carry out its delivery operations; thus, those 50 vehicles would no longer be circulating in the MCMA and 50 vehicles owned by the logistics company would carry out the delivery operations. We have not included the fact that the logistics company could possibly carry out the delivery using less than 50 vehicles because, as mentioned earlier, it is not clear whether it would be feasible; however, we acknowledge the possibility of this happening and in such a case our estimates of emissions reductions could be underestimated.

Table 6-5, 6-6 and 6-7 include freight-related NMHC, NO_x and PM_{10} emissions reductions, respectively for different levels of customers served by these logistics companies, as well as different levels of reductions of empty trips.

Table 6-5 NMHC Emissions for Different Levels of Empty Trip Reductions and Percentage of Local Fleet Usage Replaced by Logistics Companies (ktonnes)

Percentage Reduction in Empty trips	Percentage of local fleet usage replaced by Logistics Companies			
	25%	50%	75%	100%
20%	1091 (15%)	955 (26%)	815 (36%)	671 (48%)
40%	1074 (16%)	926 (28%)	779 (39%)	634 (51%)
60%	1058 (18%)	899 (30%)	747 (42%)	600 (53%)
80%	1042 (19%)	873 (32%)	717 (44%)	570 (56%)
100%	1026 (20%)	849 (34%)	689 (46%)	543 (58%)

Notes: 1) Figures are for the Future Story "Divided City"

2) The percentage of local fleet usage replaced by Logistics Companies does not include local heavy-duty vehicles.

3) Numbers in parenthesis represent emissions reductions with respect to the base case.

From table 6-5 we can draw two main observations. First, the potential amount of freight-related NMHC emissions reductions if these companies are created and function properly could be substantial. Second, emissions reductions are more sensitive to the number of customers served by these companies than to the reduction of empty trips that could be achieved. Therefore, the main benefit would be attributable to a renewal of the local freight fleet.

Table 6-6 NO_x Emissions for Different Levels of Empty Trip Reductions and Percentage of Local Fleet Usage Replaced by Logistics Companies (ktonnes)

Percentage Reduction in Empty trips	**Percentage of local fleet usage replaced by Logistics Companies**			
	25%	**50%**	**75%**	**100%**
20%	823 (5.8%)	783 (10.4%)	739 (15.4%)	689 (21.2%)
40%	823 (5.8%)	783 (10.4%)	738 (15.6%)	689 (21.2%)
60%	823 (5.8%)	783 (10.4%)	738 (15.6%)	688 (21.3%)
80%	823 (5.8%)	782 (10.5%)	737 (15.7%)	687 (21.4%)
100%	822 (5.9%)	781 (10.6%)	736 (15.8%)	687 (21.4%)

Notes: 1) Figures are for the Future Story "Divided City"
2) The percentage of local fleet usage replaced by Logistics Companies does not include local heavy-duty vehicles.
3) Numbers in parenthesis represent emissions reductions with respect to the base case.

From this table we can note that freight-related NO_x emissions reductions could also be significant. Once again, emissions reductions would mostly be attributable to the renewal of the fleet and not so much to the reduction of empty trips.

Table 6-7 PM_{10} Emissions for Different Levels of Empty Trip Reductions and Percentage of Local Fleet Usage Replaced by Logistics Companies (ktonnes)

Percentage Reduction in Empty trips	Percentage of local fleet usage replaced by Logistics Companies			
	25%	50%	75%	100%
20%	67 (0%)	67 (0%)	67 (0%)	67 (0%)
40%	67 (0%)	67 (0%)	67 (0%)	66 (1%)
60%	67 (0%)	67 (0%)	67 (0%)	66 (1%)
80%	67 (0%)	67 (0%)	67 (0%)	66 (1%)
100%	67 (0%)	67 (0%)	67 (0%)	66 (1%)

Notes: 1) Figures are for the Future Story "Divided City"

2) The percentage of local fleet usage replaced by Logistics Companies does not include local heavy-duty vehicles.

3) Numbers in parenthesis represent emissions reductions with respect to the base case.

Contrary to NMHC and NO_x, there would practically be no PM_{10} emissions reductions if these centers are created and operated properly. The reason behind this is that the most of the local private fleet is composed of light-duty and heavy-duty gasoline trucks. Diesel powered vehicles contribute the most to PM_{10} emissions. Many of this type of vehicles are included in the out of region freight fleet; thus they would not be included in this strategy. There are also diesel powered vehicles in the local freight fleet; however, many of them are used by the construction industry, which has not been considered in this strategy.

We believe that assuming that all of the local fleet usage replaced by these logistics companies would not be realistic. Likewise, assuming a 100% reduction of empty trips is not feasible. A recent study by McKinnon (2001) shows that the use of vehicle routing systems has the capability of reducing vehicle empty trips in an urban area by approximately 20%. We believe that a reasonable and conservative estimate of the percentage of the local fleet usage replaced by the Logistics Companies could be up to 50%; however, in order to determine the real percentage, it would be necessary to conduct a detailed study of the local private companies, their composition and freight transportation requirements.

If we assume that a 20% reduction in empty trips is achievable, from tables 6-5 and 6-6 we can note that freight-related NMHC and NO_x emissions reductions could amount up to 26% and 10.4%, respectively with respect to the base case. In both cases, such emissions reductions are still very high.

Estimating accurate values for the costs categories mentioned earlier for these Logistics Companies would not be possible with the data available. Following a similar reasoning than with the freight transfer centers, we have estimated by how much costs would rise from the base case by renewing and acquiring the needed number of vehicles for these Logistics Companies for different levels of fleet usage substitution, as shown in table 6-8. These costs could be viewed as a lower bound on the total costs of establishing these Logistics Companies.

Table 6-8 Total Costs of the MCMA Freight Fleet with the Creation of Logistics Companies

Percentage of local fleet usage replaced by Logistics Companies	Present Value of Total Costs of the MCMA Freight Fleet (2000-2025) in BYBMXP[1/]		
	Divided City	Changing Climates	Growth Unbound
Base Case	749	925	1356
Assuming 25% is replaced by Logistics Companies	762 (1.8%)	944 (2.0%)	1,380 (1.8%)
Assuming 50% is replaced by Logistics Companies	775 (3.5%)	962 (4.1%)	1,405 (3.6%)
Assuming 75% is replaced by Logistics Companies	789 (5.3%)	981 (6.1%)	1,429 (5.4%)
Assuming 100% is replaced by Logistics Companies	801 (6.9%)	999 (8.2%)	1,454 (7.2%)

1/ Year 2000 Billion Mexican Pesos. The discount rates are: "Divided City" = 13%; "Changing Climates" = 10%; "Growth Unbound" = 8%.They represent a social discount rate common to all future stories plus the inflation under each future story.

Notes: 1) figures in parenthesis represent the percent increase in total costs with respect to the Base Case. 2) Assuming a 20% reduction in vehicle empty trips is achieved.

From this table we can see that simply considering the fleet renewal costs could raise costs significantly from the base case. Similarly to freight transfer centers, these costs could be paid by both the public and private sectors. The government could provide the initial funds needed to establish these Logistics Companies (i.e. land acquisition and construction costs) and have them purchase the vehicles they will need to operate by offering low interest loans.

6.2.3 Combined Fleet Operational and Utilization Improvement Strategies

The three fleet operational and utilization improvement strategies presented above could be applied simultaneously. Establishing freight transfer centers and increasing the attractiveness of the railroad could be done simultaneously in order to keep a greater amount of the out of region heavy-duty vehicles from entering the MCMA than if only one of them was pursued. In fact, by doing both of them the government would create a competitive environment between these two transportation modes since any company needing to transport freight into or out of the MCMA could compare the services offered by the railroad and the freight transfer centers and decide which one best serves its requirements.

The creation of logistics companies could also be coupled with any of the other two strategies. In fact, the Logistics Companies could provide the final delivery or initial pickup required by the freight transfer centers or the intermodal terminals.

The benefits, in terms of emissions reductions, that could be achieved by implementing these strategies simultaneously are difficult to estimate. We could start by assuming that they would be equal to the sum of the emissions reductions of each strategy; however, this might prove not to be accurate. The same could be said regarding the costs of each strategy. For instance, if freight transfer centers are established, it will be necessary to acquire a certain number of light-duty vehicles to perform the deliveries and pick ups within the MCMA, as well as acquiring land and constructing the necessary facilities to provide competitive services. Likewise, if Logistics Companies are created, a certain number of light-duty vehicles will have to be acquired and new facilities might also have to be built. However, if both strategies are implemented simultaneously, it could be possible that the logistics companies provide the final deliveries or initial pick ups required by the freight transfer centers. If they manage to this efficiently, it could further be possible that the total number of light-duty vehicles needed is less than what it would be when considering each strategy individually. Furthermore, other costs, such as construction costs, labor costs and technology acquisition costs might also be lower when both strategies are implemented simultaneously than the sum of each one of them individually. With the data available, it is not possible to model these nonlinearities in terms of emissions and costs.

The impact of these nonlinearities on emissions could prove not to be very large. It could be possible that the real amount of emissions reductions achieved by implementing both strategies simultaneously is close to the sum of their individual emissions reductions. For instance, our analysis of freight transfer centers showed us that having a greater or lesser number of vehicle-km for light-duty vehicles traveling in the MCMA would not change substantially our original estimates of NMHC, NO_x and PM_{10} emission levels. In order to have an estimate of the potential benefit of implementing these strategies simultaneously, we decided to quantify their emissions reductions as the sum of their individual emissions reductions. We have quantified NMHC, NOx and PM_{10} emissions for different percentages of out of region heavy-duty vehicles kept from circulating in the MCMA, as well as for different percentages of local fleet usage substitution by Logistics Companies. Our results are shown in tables 6-9, 6-10 and 6-11.

Table 6-9 Potential NMHC Emissions Reductions by Keeping Out of Region Heavy-Duty Vehicles from Circulating in the MCMA and Creating Logistics Companies

Percentage of Out of Region Heavy-Duty Vehicles Kept Out	Percentage of local fleet usage replaced by Logistics Companies				
	0%	25%	50%	75%	100%
0%	1283 (0%)	1091 (15%)	955 (26%)	815 (36%)	671 (48%)
25%	1271 (1%)	1079 (16%)	943 (27%)	803 (37%)	659 (49%)
50%	1260 (2%)	1068 (17%)	932 (27%)	792 (38%)	648 (49%)
75%	1250 (3%)	1058 (18%)	922 (28%)	782 (39%)	638 (50%)
100%	1237 (4%)	1045 (19%)	909 (29%)	769 (40%)	625 (51%)

Notes: 1) Figures are for Future Story “A Divided City”; 2) assuming a 20% reduction in empty trips; 3) Numbers in parenthesis represent reductions with respect to base case

From this table we can confirm the fact that freight-related NMHC emissions reductions would be attributable to the creation of the Logistics Companies. In fact, freight-related NMHC emissions reductions could amount only up to 4% if all out of region heavy-duty vehicles are kept from circulating in the MCMA.

Table 6-10 Potential NO_x Emissions Reductions by Keeping Out of Region Heavy-Duty Vehicles from Circulating in the MCMA and Creating Logistics Companies

Percentage of Out-of Region Heavy Duty Vehicles Kept Out	Percentage of local fleet usage replaced by Logistics Companies				
	0%	**25%**	**50%**	**75%**	**100%**
0%	874 (0%)	823 (6%)	783 (10%)	739 (15%)	689 (21%)
25%	842 (4%)	791 (9%)	751 (14%)	707 (19%)	657 (25%)
50%	811 (7%)	760 (13%)	720 (18%)	676 (23%)	626 (28%)
75%	786 (10%)	735 (16%)	695 (20%)	651 (26%)	601 (31%)
100%	749 (14%)	698 (20%)	658 (25%)	614 (30%)	564 (35%)

Notes: 1) Figures are for Future Story "A Divided City"; 2) assuming a 20% reduction in empty trips; 3) Numbers in parenthesis represent reductions with respect to base case

From table 6-10 we can note that freight-related NO_x emissions could decrease considerably when considering implementing strategies simultaneously. Thus, this type of emissions is driven by both types of strategies, keeping out of region heavy-duty vehicles from circulating in the MCMA and creating Logistics Companies.

Table 6-11 Potential PM_{10} Emissions Reductions by Keeping Out of Region Heavy-Duty Vehicles from Circulating in the MCMA and Creating Logistics Companies

Percentage of Out-of Region Heavy Duty Vehicles Kept Out	Percentage of local fleet usage replaced by Logistics Companies				
	0%	25%	50%	75%	100%
0%	67 (0%)	67 (0%)	67 (0%)	67 (0%)	67 (0%)
25%	62 (7%)	62 (7%)	62 (7%)	62 (7%)	62 (7%)
50%	57 (15%)	57 (15%)	57 (15%)	57 (15%)	57 (15%)
75%	54 (19%)	54 (19%)	54 (19%)	54 (19%)	54 (19%)
100%	48 (28%)	48 (28%)	48 (28%)	48 (28%)	48 (28%)

Notes: 1) Figures are for Future Story “A Divided City”; 2) assuming a 20% reduction in empty trips; 3) Numbers in parenthesis represent reductions with respect to base case

From this table we can see that freight-related PM_{10} emissions reductions would only be achieved by keeping heavy-duty vehicles from circulating in the MCMA since we would not have any emissions reductions for any percentage of the local fleet usage replaced by the Logistics Companies.

Based on our analysis and given the assumptions we have made so far we can note that keeping out of region heavy-duty vehicles from circulating in the MCMA could have a considerable impact on NO_x and PM_{10} emissions, but practically none on NMHC emissions. Likewise, creating Logistics Companies could have a considerable impact on NO_x and NMHC emissions, but practically none on PM_{10} emissions. These two observations could suggest that any nonlinearities that we missed on our analysis (when strategies are implemented simultaneously) would probably not have a significant impact on emission levels for NMHC and PM_{10}, but could have for NO_x.

6.3 Combined Vehicle Technology and Fuel Quality Improvement Strategies & Fleet Operational and Utilization Improvement Strategies

In Chapter Five we analyzed a series of strategies aimed at reducing emissions based on vehicle technology and fuel quality improvements. We are now interested in evaluating the effectiveness of combining these type of strategies with the ones we are analyzing in this chapter. For instance, we could establish the freight transfer centers and have the light-duty vehicles making the deliveries or pick ups within the MCMA be powered by natural gas instead of gasoline. By doing this, we could combine the potential of both types of strategies to achieve both sustainable and sustained emissions reductions.

We will analyze three different strategies that combine the use of vehicle technology and fuel quality improvements, as well as fleet operational and utilization improvements. These strategies are shown in table 6-12.

Table 6-12 Combined Vehicle Technology and Fuel Quality Improvements & Fleet Operational and Utilization Improvement Strategies

Combined Strategies	Strategies Included	Key Pollutant Reduction	Deployment Schedule	Number of vehicles included
6	Stricter Emission Standards for New Heavy-Duty Diesel Vehicles	NO_x PM_{10} NMHC	Starts: 2006 Ends: 2015	N/A
	Keeping Out of Region Heavy Duty Vehicles from Circulating in the MCMA by Establishing Freight Transfer Centers or Increasing Railroad Utilization	NOx PM_{10} NHMC	Starts: 2004 Ends:2008	50% of all heavy-duty vehicles entering/leaving the MCMA
	Deliveries and pickups made with light-duty natural gas vehicles	NMHC	Starts: 2004 Ends: 2010	
7	Stricter Emission Standards for New Heavy-Duty Diesel Vehicles	NO_x PM_{10} NMHC	Starts: 2006 Ends: 2015	N/A
	All Heavy-Duty Diesel Vehicles Must be at Most 15 years old.	NO_x PM_{10}	Starts: 2004 Ends: 2010	N/A
	All Heavy-Duty Gasoline Vehicles Must be at Most 15 years old.	NO_x NMHC	Starts: 2004 Ends: 2010	N/A
	Keeping Out of Region Heavy Duty Vehicles from Circulating in the MCMA by Establishing Freight Transfer Centers or Increasing Railroad Utilization	NOx PM_{10} NHMC	Starts: 2004 Ends:2008	50% of all heavy-duty vehicles entering/leaving the MCMA
	Deliveries and pickups made with light-duty natural gas vehicles	NMHC	Starts: 2004 Ends: 2010	

8	Stricter Emission Standards for New Heavy-Duty Diesel Vehicles	NO_x PM10 NMHC	Starts: 2006 Ends: 2015	N/A
	All Heavy-Duty Diesel Vehicles Must be at Most 15 years old.	NO_x PM_{10}	Starts: 2004 Ends: 2010	N/A
	All Heavy-Duty Gasoline Vehicles Must be at Most 15 years old.	NO_x NMHC	Starts: 2004 Ends: 2010	N/A
	Creation of Integrated Logistics Companies	NO_x NMHC	Starts: 2004 Ends: 2010	50% of all local light-duty vehicles
	Keeping Out of Region Heavy Duty Vehicles from Circulating in the MCMA by Establishing Freight Transfer Centers or Increasing Railroad Utilization	NOx PM_{10}	Starts: 2004 Ends:2008	50% of all heavy-duty vehicles entering/leaving the MCMA
	Deliveries and pickups made with light-duty natural gas vehicles	NMHC	Starts: 2004 Ends: 2010	

The first of these new combined strategies (combined strategy six[68]) is aimed primarily at reducing PM_{10} emissions. As such, it includes the implementation of stricter emissions standards for new heavy-duty diesel vehicles, as well as keeping out of region heavy-duty vehicles form circulating in the MCMA by establishing freight transfer centers and/or increasing the railroad's utilization for goods entering or leaving the MCMA. In this strategy the light-duty vehicles making the deliveries and pickups within the MCMA would be powered with natural gas. By doing this, we could achieve substantial PM_{10} and NO_x emissions reductions without increasing NMHC emissions or CO_2 emissions substantially.

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[68] In Chapter Five we analyzed five combined strategy; thus, we start with combined strategy six in this chapter.

Establishing freight transfer centers or increasing the railroad's utilization for transporting goods entering or leaving the MCMA could potentially keep out of region heavy-duty vehicles from circulating within the MCMA; however, these strategies would not help in reducing emissions from heavy-duty vehicles from the local freight fleet. In order to account for the local heavy-duty fleet combined strategy seven include two strategies that set an age limit of 15 years old for all heavy-duty diesel and gasoline vehicles circulating in the MCMA.

Combined strategy eight includes setting age limits for heavy-duty diesel and gasoline vehicles as well as implementing stricter emissions standards for new heavy-duty diesel vehicles. In addition, it includes keeping out of region heavy-duty vehicles form circulating in the MCMA by establishing freight transfer centers and/or increasing the railroad's utilization for goods entering or leaving the MCMA. The light-duty vehicles making the deliveries and pickups within the MCMA would be powered with natural gas. Furthermore, the creation of Logistics Companies is also included in this combined strategy.

As mentioned earlier, freight transfer centers would presumably improve the overall level of service provided by its users to their customers. Therefore, high value, time sensitive freight could be considered as potential freight to use these centers since it is most sensitive to level of service improvements. A survey of freight vehicles circulating in highways, as well freight railroad operations in Mexico published by the Mexican Institute of Transportation (IMT) indicates that approximately 50% of all freight entering or leaving the MCMA in 1996 was high value freight[69]. Based on this, we will assume that 50% of all out of region heavy-duty vehicles would be kept out of the MCMA by establishing freight centers and/or increasing the railroad's utilization for transporting goods entering or leaving the MCMA.

Logistics Companies would also increase the level of service offered to companies. Therefore, high value freight could also be considered as potential freight to be carried by these companies. We have no data regarding the percentage of high value freight with respect to the total amount of freight moved within the MCMA; however, if we consider that the MCMA is an urban area and that it contributes to nearly 30% of the

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[69] Instituto Mexicano del Transporte (1994)

Gross Domestic Product of Mexico, it seems reasonable to believe that a considerable percentage of the freight moving within the MCMA has a high value. We will assume that Logistics Companies would substitute 50% of the local fleet usage. Furthermore, based on the fact that the use of vehicle routing systems has the capability of reducing freight vehicle empty trips in an urban area by approximately 20%[70] we will assume that such decrease would be achieved in the MCMA. We will conduct our initial analysis based on these assumptions and revise their implications later on.

The emissions reductions that can be achieved with these combined strategies will not be determined by the sum of emissions reductions of the individual strategies included in them. For instance, if we implement individually the age limit for heavy-duty diesel and gasoline vehicles we would get a certain amount of emissions reductions. Likewise, implementing freight transfer centers would also give us a certain amount of emissions reductions. However, by implementing them simultaneously, the total amount of emissions reductions would not be the sum of these two strategies simply because the age limit would apply to a lower number of heavy-duty diesel and gasoline vehicles circulating in the MCMA, since some of them would be kept out of the city due to the installation of the freight transfer centers; thus the total amount of emissions reductions would be less when implemented simultaneously than the sum of them when implemented individually. The same could be said regarding the impact on emissions of applying stricter emission standards for new heavy-duty diesel vehicles individually and in conjunction with the establishment of freight transfer centers or increasing the railroad's utilization for goods entering or leaving the MCMA.

Having specified these new combined strategies we can now estimate their capability of achieving emissions reductions for all three pollutants. Figures 6-8, 6-9 and 6-10 illustrate the cumulative emissions from year 2000 until 2025, as well as the percentage reduction for each combined strategy.

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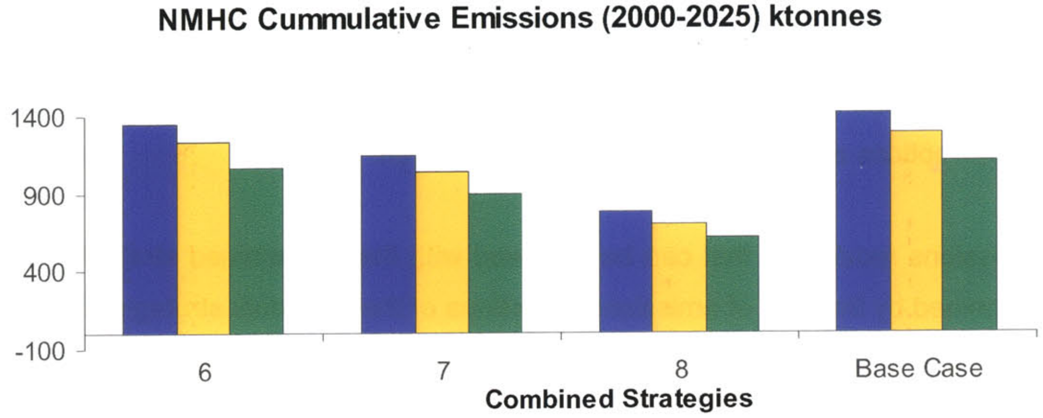
[70] McKinnon (2001)

Figure 6-8 NMHC Emissions for Combined Vehicle Technology and Fuel Quality Improvements & Fleet Operational and Utilization Improvement Strategies



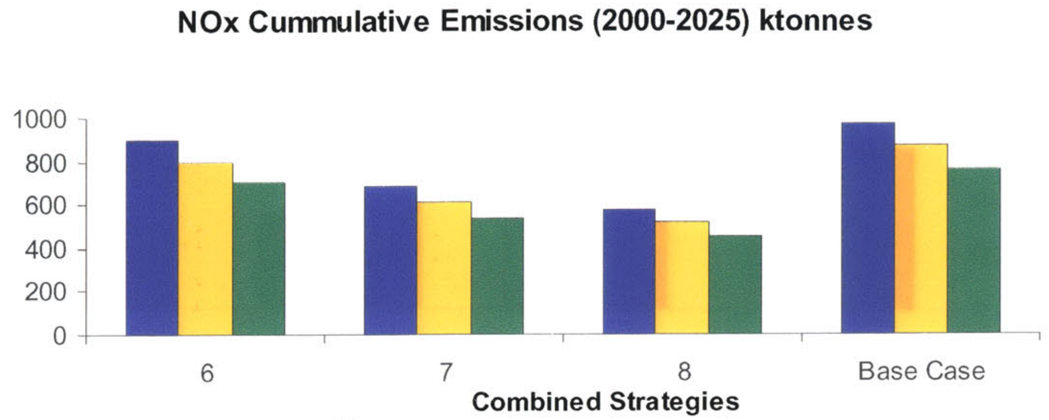
Emissions' Reductions (%)

DC	4%	19%	45%
CC	4%	19%	44%
GU	4%	19%	45%

Notes:
1) DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound"

From figure 6-8 we can note that under the assumptions made, combined strategy eight could achieve a reduction of up to 45% of freight-related NMHC emissions with respect to the base case. Combined strategies seven could be potentially achieve a 19% freight-related NMHC emissions reductions, while combined strategy six would not have a significant impact on these pollutant's emissions.

Figure 6-9 NO_x Emissions for Combined Vehicle Technology and Fuel Quality Improvements & Fleet Operational and Utilization Improvement Strategies



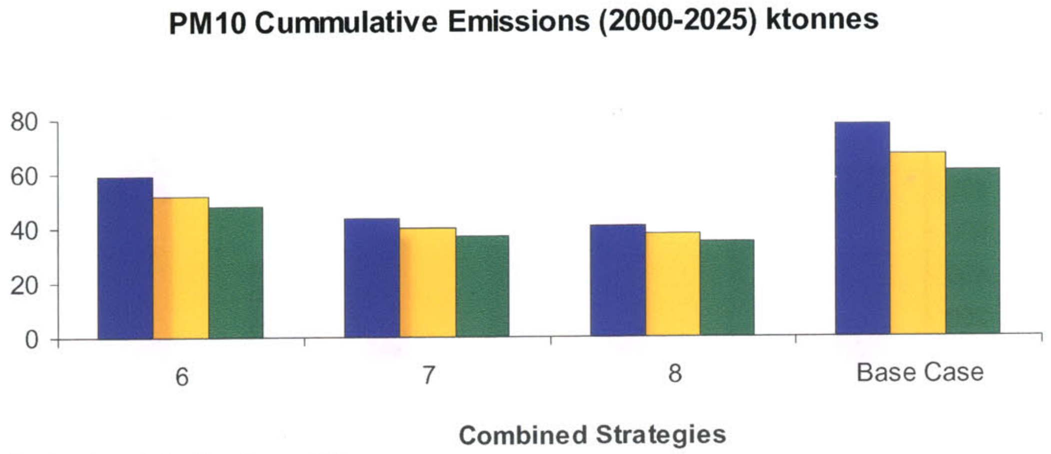
Emissions' Reductions (%)

DC	9%	30%	41%
CC	8%	30%	41%
GU	8%	31%	41%

Notes:
1) DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound"

From this figure we can note that given our assumptions, freight-related NO_x emissions could be substantially reduced if combined strategies seven or eight are implemented. The greatest freight emissions reductions could amount up to 41% with respect to the base case (combined strategy eight).

Figure 6-10 PM$_{10}$ Emissions for Combined Vehicle Technology and Fuel Quality Improvements & Fleet Operational and Utilization Improvement Strategies



Emissions' Reductions (%)

DC	22%	40%	43%
CC	21%	39%	43%
GU	24%	44%	47%

🟨 Divided City 🟩 Changing Climates 🟦 Growth Unbound

Notes:
1) DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound"

Figure 6-10 shows that given our assumptions, all these combined strategies could achieve substantial PM$_{10}$ emissions reductions for freight with respect to the base case. Strategies seven and eight would present the greatest emissions reductions.

Having estimated these combined strategies capability of achieving substantial emissions reductions, we still need to determine if such reductions will be sustainable in the future; thus we are interested in determining if their capability of achieving low pollutant emissions in future years despite the increase of freight traffic in the MCMA (vehicle-km).

We have estimated the level of emissions for each pollutant in the year 2025 and compared it to its level in the year 2000, as shown in table 6-13.

Table 6-13 Percentage Increase/Decrease of Year 2025 Emission Levels with Respect to Year 2000 for Combined Vehicle Technology and Fuel Quality Improvement Strategies & Fleet Operational and Utilization Improvement Strategies

Combined Strategies	NMHC			NO_x			PM_{10}		
	DC	CC	GU	DC	CC	GU	DC	CC	GU
6	71%	29%	101%	68%	31%	102%	14%	-3%	41%
7	44%	8%	71%	21%	-7%	47%	-61%	-68%	-53%
8	-8%	-33%	9%	-8%	-30%	11%	-64%	-70%	-56%

Note: DC= "Divided City"; CC= "Changing Climates"; 3) GU= "Growth Unbound".

From this table we can make several observations. First, no combined strategy would be capable of achieving sustained emissions reductions under all three future stories and for all pollutants due to the increase of freight traffic growth (vehicle-km) in the MCMA. Second, combined strategies seven and eight would be capable of achieving sustainable PM_{10} emissions reductions for all three future stories. Third, only combined strategy eight would be able to achieve sustainable NMHC; however, this would only occur under future stories "Divided City" and "Changing Climate".

In Chapter Five we discussed the possibility of strategies not being implemented as originally planned. When evaluating these new combined strategies we are interested in determining their performance in case they are not implemented as originally planned. Furthermore, we are also interested in testing their performance in case the assumptions we made so far do not occur. For instance, we have assumed that 50% of all out of region heavy-duty vehicles would be kept from circulating in the MCMA. Since we cannot know at this time whether that would be possible, we will test combined strategies six, seven and eight's performance if a lesser or higher amount of vehicles is actually kept out.

Table 6-14 lists the changes in the implementation of each combined strategy, as well as on our assumptions that we will test.

Table 6-14 Vehicle Technology and Fuel Quality Improvement Strategies and Fleet Operational & Utilization Improvement Strategies Changes in their Implementation and Assumptions

Combined Strategies	Strategies Included	Implementation/Assumption Changes
6	Stricter Emission Standards for New Heavy-Duty Diesel Vehicles	More lenient deployment schedule. Starts:2006 Ends:2020
	Keeping Out of Region Heavy Duty Vehicles from Circulating in the MCMA by Establishing Freight Transfer Centers or Increasing Railroad Utilization	Different percentages of out of region heavy-duty vehicles entering/leaving the MCMA (25%, 50%, 75%, 100%).
	Extra freight demand of light-duty vehicles met with light-duty natural gas vehicles	
7	Stricter Emission Standards for New Heavy-Duty Diesel Vehicles	More lenient deployment schedule. Starts:2006 Ends:2020
	All Heavy-Duty Diesel Vehicles Must be at Most 15 years old.	The maximum age increases to 20 years instead of 15 years.
	All Heavy-Duty Gasoline Vehicles Must be at Most 15 years old.	
	Keeping Out of Region Heavy Duty Vehicles from Circulating in the MCMA by Establishing Freight Transfer Centers or Increasing Railroad Utilization	Different percentages of out of region heavy-duty vehicles entering/leaving the MCMA (25%, 50%, 75%, 100%).
	Extra freight demand of light-duty vehicles met with light-duty natural gas vehicles	
8	Stricter Emission Standards for New Heavy-Duty Diesel Vehicles	More lenient deployment schedule. Starts:2006 Ends:2020
	All Heavy-Duty Diesel Vehicles Must be at Most 15 years old.	The maximum age increases to 20 years instead of 15 years.
	All Heavy-Duty Gasoline Vehicles Must be at Most 15 years old.	

	Creation of Integrated Logistics Companies	1. Different percentages of local fleet usage replaced by logistics companies ((25%, 50%, 75%, 100%). 2. We will not test different percentages of empty tip reductions (5%, 10%)
	Keeping Out of Region Heavy Duty Vehicles from Circulating in the MCMA by Establishing Freight Transfer Centers or Increasing Railroad Utilization	Different percentages of out of region heavy-duty vehicles entering/leaving the MCMA (25%, 50%, 75%, 100%).
	Extra freight demand of light-duty vehicles met with light-duty natural gas vehicles	

For combined strategy six we will test its potential of achieving emissions reductions if two changes occur. First, we will consider a more lenient deployment schedule for the implementation of stricter emissions standards for new heavy-duty diesel vehicles. Second, a different amount of out of region heavy-duty vehicles is kept from circulating in the MCMA.

For combined strategy seven, we will test its potential with respect to the changes included in combined strategy six, as well as if the heavy-duty vehicles don't comply with the 15 year age limit. Specifically, we will consider the effect of having the real age limit rise to 20 years.

For combined strategy eight we will test the changes described above, as well as what would be the impact of having different percentages of the local fleet usage replaced by the Logistics Companies. In addition, we will test its performance for different percentage decreases in empty trip reductions.

Table 6-15 Combined Strategy Six Emissions for Changes in its Implementation and Assumptions

Percentage of OR Heavy-Duty Vehicles Kept Out	**Deployment Schedule of Stricter Emission Standards for New HDDV**	**NMHC**			**NO_x**			**PM_{10}**		
		DC	**CC**	**GU**	**DC**	**CC**	**GU**	**DC**	**CC**	**GU**
25%	**a.** Original	1252 (2%)	1078 (2%)	1374 (2%)	831 (5%)	726 (4%)	928 (5%)	56 (16%)	51 (16%)	64 (18%)
	b. More Lenient Deployment Schedule	1255 (2%)	1081 (2%)	1379 (2%)	837 (4%)	731 (4%)	936 (4%)	57 (15%)	52 (15%)	65 (17%)
50%	**a.** Original	1231 (4%)	1062 (4%)	1353 (4%)	799 (9%)	701 (8%)	895 (8%)	52 (22%)	48 (21%)	59 (24%)
	b. More Lenient Deployment Schedule	1234 (4%)	1065 (3%)	1358 (4%)	804 (8%)	706 (7%)	903 (7%)	53 (21%)	49 (20%)	60 (23%)
75%	**a.** Original	1210 (6%)	1047 (5%)	1333 (5%)	766 (12%)	676 (11%)	863 (11%)	47 (30%)	44 (28%)	54 (31%)
	b. More Lenient Deployment Schedule	1212 (6%)	1049 (5%)	1337 (5%)	770 (12%)	680 (11%)	869 (11%)	48 (28%)	45 (26%)	55 (29%)
100%	**a.** Original	1189 (7%)	1031 (7%)	1312 (7%)	733 (16%)	651 (14%)	830 (15%)	43 (36%)	40 (34%)	49 (37%)
	b. More Lenient Deployment Schedule	1191 (7%)	1033 (6%)	1315 (7%)	737 (16%)	655 (14%)	835 (14%)	44 (34%)	41 (33%)	50 (36%)

Notes: 1) DC= "Divided City"; CC= "Changing Climates"; GU= "Growth Unbound".
2) Numbers in parenthesis represent percentage reductions with respect to the base case

From table 6-14 we can note that combined strategy six's emissions reductions are driven by the amount of out of region heavy-duty vehicles that are kept out of the MCMA. If the deployment schedule of the implementation of stricter emissions standards for new heavy-duty vehicles is more lenient than the initially proposed, emissions would not increase significantly.

Table 6-16 Combined Strategy Six Percentage Increase/Decrease of Year 2025 Emission Levels with Respect to Year 2000 for Changes in its Implementation and Assumptions

Percentage of OR Heavy-Duty Vehicles Kept Out	Deployment Schedule of Stricter Emission Standards for New HDDV	NMHC			NO_x			PM_{10}		
		DC	CC	GU	DC	CC	GU	DC	CC	GU
25%	a. Original	73%	31%	103%	74%	35%	108%	26%	7%	56%
	b. More Lenient Deployment Schedule	75%	32%	105%	78%	38%	113%	34%	14%	67%
50%	a. Original	71%	29%	101%	68%	31%	102%	14%	-3%	41%
	b. More Lenient Deployment Schedule	72%	30%	102%	71%	34%	106%	20%	4%	51%
75%	a. Original	68%	27%	98%	61%	27%	95%	1%	-12%	27%
	b. More Lenient Deployment Schedule	69%	28%	99%	64%	29%	99%	7%	-6%	36%
100%	a. Original	65%	26%	95%	55%	23%	89%	-12%	-21%	13%
	b. More Lenient Deployment Schedule	66%	27%	96%	57%	25%	92%	-7%	-16%	20%

Notes: 1) DC= “Divided City”; CC= “Changing Climates”; GU= “Growth Unbound”.

From table 6-16 we can note that sustained emissions reductions for NMHC and NO_x would not be significantly different if the deployment schedule of the implementation of stricter emission standards for new heavy-duty diesel vehicles was more lenient than originally proposed. However, such change in deployment schedule can have a significant impact on future PM_{10} emission levels. For instance, if 50% of out-of region heavy-duty vehicles are kept out of the MCMA and the initial deployment schedule for stricter emission standards is followed, emission levels in year 2025 would be lower than in year 2000; however, if such deployment schedule is not followed, emission levels in year 2025 would be higher than in year 2000.

Table 6-17 Combined Strategy Seven Emissions for Changes in its Implementation and Assumptions

Percentage of OR Heavy-Duty Vehicles Kept Out	Deployment Schedule of Stricter Emission Standards for New HDDV	NMHC			NO_x			PM_{10}		
		DC	CC	GU	DC	CC	GU	DC	CC	GU
25%	a. Original	1074 (16%)	924 (16%)	1181 (16%)	664 (24%)	579 (24%)	741 (24%)	45 (33%)	42 (31%)	51 (35%)
	b. More Lenient Deployment Schedule	1082 (16%)	932 (16%)	1192 (15%)	678 (22%)	592 (22%)	760 (22%)	48 (28%)	44 (28%)	54 (31%)
	c. More Lenient Deployment Schedule & Age increase to 20 years	1107 (14%)	955 (13%)	1220 (13%)	709 (19%)	620 (18%)	794 (19%)	51 (24%)	47 (23%)	58 (26%)
50%	a. Original	1053 (18%)	908 (18%)	1160 (18%)	631 (28%)	554 (27%)	708 (27%)	41 (39%)	38 (38%)	46 (41%)
	b. More Lenient Deployment Schedule	1061 (17%)	916 (17%)	1171 (17%)	645 (26%)	567 (25%)	726 (26%)	44 (34%)	40 (34%)	49 (37%)
	c. More Lenient Deployment Schedule & Age increase to 20 years	1086 (15%)	939 (15%)	1199 (15%)	675 (23%)	595 (22%)	761 (22%)	47 (30%)	43 (30%)	53 (32%)
75%	a. Original	1032 (20%)	893 (19%)	1140 (19%)	599 (31%)	530 (30%)	676 (31%)	37 (45%)	34 (44%)	41 (47%)

	b. More Lenient Deployment Schedule	1039 (19%)	900 (18%)	1150 (18%)	611 (30%)	541 (29%)	693 (29%)	39 (42%)	37 (39%)	44 (44%)
	c. More Lenient Deployment Schedule & Age increase to 20 years	1064 (17%)	923 (16%)	1178 (16%)	642 (27%)	569 (25%)	727 (25%)	42 (37%)	39 (36%)	48 (38%)
100%	**a.** Original	1011 (21%)	877 (20%)	1119 (21%)	566 (35%)	505 (34%)	643 (34%)	32 (52%)	31 (49%)	36 (54%)
	b. More Lenient Deployment Schedule	1018 (21%)	884 (20%)	1129 (20%)	578 (34%)	516 (32%)	659 (32%)	35 (48%)	33 (46%)	39 (50%)
	c. More Lenient Deployment Schedule & Age increase to 20 years	1043 (19%)	907 (18%)	1157 (18%)	609 (30%)	544 (28%)	693 (29%)	38 (43%)	36 (41%)	43 (45%)

Notes: 1) DC= “Divided City”; CC= “Changing Climates”; GU= “Growth Unbound”.
2) Numbers in parenthesis represent percentage reductions with respect to the base case

From this table we can make several observations. First, combined strategy seven’s capability of achieving NMHC emissions reductions would not be seriously hindered if the age limit increased to 20 years and the deployment schedule for the implementation of stricter emission standards for new heavy-duty diesel vehicles was more lenient than originally planned. Second, freight-related NO_x and PM_{10} emissions reductions would be approximately 5% and 10% less, respectively, if the age limit increases and the deployment schedule for the implementation of stricter emission standards was more lenient than originally planned. Third, emissions reductions for all pollutants could be substantial if at least 50% of all out of region heavy-duty vehicles are kept from circulating in the MCMA even if the changes in the implementation occur.

Table 6-18 Combined Strategy Seven Percentage Increase/Decrease of Year 2025 Emission Levels with Respect to Year 2000 for Changes in its Implementation and Assumptions

Percentage of OR Heavy-Duty Vehicles Kept Out	Deployment Schedule of Stricter Emission Standards for New HDDV	NMHC			NO_x			PM_{10}		
		DC	CC	GU	DC	CC	GU	DC	CC	GU
25%	**a**. Original	49%	11%	76%	33%	1%	60%	-40%	-52%	-29%
	b. More Lenient Deployment Schedule	52%	14%	80%	41%	8%	70%	-26%	-39%	-10%
	c. More Lenient Deployment Schedule & Age increase to 20 years	54%	16%	82%	44%	11%	75%	-6%	-22%	16%
50%	**a**. Original	46%	10%	73%	26%	-3%	53%	-53%	-61%	-43%
	b. More Lenient Deployment Schedule	49%	12%	77%	34%	4%	64%	-39%	-49%	-25%
	c. More Lenient Deployment Schedule & Age increase to 20 years	51%	14%	79%	37%	7%	68%	-20%	-32%	-1%
75%	**a**. Original	44%	8%	70%	20%	-7%	47%	-66%	-71%	-57%

	b. More Lenient Deployment Schedule	46%	10%	74%	27%	-1%	57%	-53%	-60%	-40%
	c. More Lenient Deployment Schedule & Age increase to 20 years	48%	12%	76%	30%	2%	61%	-33%	-42%	-15%
100%	**a.** Original	41%	6%	68%	13%	-11%	40%	-78%	-80%	-71%
	b. More Lenient Deployment Schedule	43%	9%	71%	20%	-5%	50%	-67%	-70%	-56%
	c. More Lenient Deployment Schedule & Age increase to 20 years	45%	10%	73%	23%	-2%	54%	-47%	-52%	-30%

Notes: 1) DC= “Divided City”; CC= “Changing Climates”; GU= “Growth Unbound”

From this table we can make several observations. First, NMHC emission levels in year 2025 would be higher than those of year 2000 under all changes considered and under all future stories. Second, PM_{10} 2025 emission levels would be lower than those of year 2000 under all changes considered and all future stories, except one future story "Growth Unbound" and if three different things occur: 1) only 25% of all out of region heavy-duty vehicles are kept from circulating in the MCMA; 2) the deployment schedule of the implementation of stricter emission standards for new heavy-duty diesel vehicles was more lenient than originally planned; and 3) the age limit set for heavy-duty diesel and gasoline vehicles circulating in the MCMA was 20 instead of 15 years.

Table 6-19 Combined Strategy Eight NMHC Emissions for Changes in its Implementation and Assumptions and for Future Story "A Divided City"

Percentage of Out-of Region Heavy Duty Vehicles Kept Out	Percentage of local fleet usage replaced by Logistics Companies			
	25%	50%	75%	100%
25%	923 (30%)	791 (38%)	652 (49%)	508 (60%)
50%	902 (32%)	770 (40%)	631 (51%)	487 (62%)
75%	880 (33%)	748 (42%)	609 (53%)	465 (64%)
100%	859 (34%)	727 (43%)	588 (54%)	444 (65%)

Notes: Figures are for Future Story "A Divided City"; 2) Figures are assuming a) a more lenient deployment schedule for the implementation of stricter emission standards for new heavy-duty diesel vehicles and b) an age limit of 20 years for heavy-duty diesel and gasoline vehicles circulating in the MCMA; and 3) 10% reduction in empty trips.

From this table we can note that combined strategy eight could achieve substantial NMHC emissions reductions even when considering the implementation changes presented in table 6-14. If only 25% of all out of region heavy-duty vehicles are kept from circulating in the MCMA and 25% of the local fleet usage is replaced by the Logistics Companies, approximately a 30% of freight-related NMHC emissions reductions could be possible.

Table 6-20 Combined Strategy Eight NO_x Emissions for Changes in its Implementation and Assumptions and for Future Story "A Divided City"

Percentage of Out-of Region Heavy Duty Vehicles Kept Out	Percentage of local fleet usage replaced by Logistics Companies			
	25%	50%	75%	100%
25%	658 (22%)	619 (29%)	574 (34%)	525 (40%)
50%	624 (26%)	585 (33%)	540 (38%)	491 (44%)
75%	591 (29%)	552 (37%)	507 (42%)	458 (48%)
100%	558 (33%)	519 (41%)	474 (46%)	425 (51%)

Notes: Figures are for Future Story "A Divided City"; 2) Figures are assuming a) a more lenient deployment schedule for the implementation of stricter emission standards for new heavy-duty diesel vehicles and b) an age limit of 20 years for heavy-duty diesel and gasoline vehicles circulating in the MCMA; and 3) 10% reduction in empty trips.

Similarly to NMHC emissions, from this we can note that combined strategy eight could achieve substantial freight-related NO_x emissions reductions even when considering the implementation changes presented in table 6-14. If only 25% of all out of region heavy-duty vehicles are kept from circulating in the MCMA and 25% of the local fleet usage is replaced by the Logistics Companies, approximately a 22% in freight-related NO_x emissions reductions could be possible.

Table 6-21 Combined Strategy Eight PM_{10} Emissions for Changes in its Implementation and Assumptions and for Future Story "A Divided City"

Percentage of Out-of Region Heavy Duty Vehicles Kept Out	Percentage of local fleet usage replaced by Logistics Companies			
	25%	50%	75%	100%
25%	51 (27%)	51 (27%)	51 (27%)	51 (27%)
50%	47 (33%)	47 (33%)	47 (33%)	47 (33%)
75%	42 (40%)	42 (40%)	42 (40%)	42 (40%)
100%	38 (46%)	38 (46%)	38 (46%)	38 (46%)

Notes: Figures are for Future Story "A Divided City"; 2) Figures are assuming a) a more lenient deployment schedule for the implementation of stricter emission standards for new heavy-duty diesel vehicles and b) an age limit of 20 years for heavy-duty diesel and gasoline vehicles circulating in the MCMA; and 3) 10% reduction in empty trips.

From this table we can note that freight-related PM_{10} emissions reductions could be substantial under combined strategy eight even when considering the changes presented in table 6-14.

Table 6-22 Combined Strategy Eight Percentage Increase/Decrease of Year 2025 NMHC Emission Levels with Respect to Year 2000 for Changes in its Implementation and Assumptions

Percentage of Out-of Region Heavy Duty Vehicles Kept Out	Percentage of local fleet usage replaced by Logistics Companies			
	25%	50%	75%	100%
25%	26%	4%	-6%	-35%
50%	23%	1%	-8%	-38%
75%	20%	-1%	-11%	-41%
100%	18%	-4%	-14%	-44%

Notes: Figures are for Future Story "A Divided City"; 2) Figures are assuming a more lenient deployment schedule for the implementation of stricter emission standards for new heavy-duty diesel vehicles and assuming an age limit of 20 years.

From this table we can note that sustained NMHC emissions reductions would only be possible if at least 50% of the local fleet usage is replaced by the Logistics Companies and 75% of the out of region heavy-duty vehicles are kept from circulating in the MCMA. Furthermore, if 75% of the local fleet usage is replaced by the Logistics Companies, then sustained emissions reductions could be achieved even when considering the changes presented in table 6-14.

Table 6-23 Combined Strategy Eight Percentage Increase/Decrease of Year 2025 NO_x Emission Levels with Respect to Year 2000 for Changes in its Implementation and Assumptions

Percentage of Out-of Region Heavy Duty Vehicles Kept Out	**Percentage of local fleet usage replaced by Logistics Companies**			
	25%	**50%**	**75%**	**100%**
25%	29%	16%	11%	-6%
50%	22%	9%	4%	-13%
75%	15%	3%	-3%	-20%
100%	8%	-4%	-10%	-27%

Notes: Figures are for Future Story "A Divided City"; 2) Figures are assuming a more lenient deployment schedule for the implementation of stricter emission standards for new heavy-duty diesel vehicles and assuming an age limit of 20 years.

From this table we can note that sustained NO_x emissions reductions would only be achievable for a high percentage of local fleet usage replaced by the Logistics Companies. In fact, when considering the changes presented in table 6-14, in order to get sustained emission reductions, at least 75% of the local fleet usage would have to be replaced by the Logistics Companies.

Table 6-24 Combined Strategy Eight Percentage Increase/Decrease of Year 2025 PM_{10} Emission Levels with Respect to Year 2000 for Changes in its Implementation and Assumptions

Percentage of Out-of Region Heavy Duty Vehicles Kept Out	**Percentage of local fleet usage replaced by Logistics Companies**			
	25%	**50%**	**75%**	**100%**
25%	-7%	-8%	-8%	-9%
50%	-21%	-21%	-22%	-22%
75%	-34%	-35%	-35%	-36%
100%	-48%	-48%	-49%	-50%

Notes: Figures are for Future Story "A Divided City"; 2) Figures are assuming a more lenient deployment schedule for the implementation of stricter emission standards for new heavy-duty diesel vehicles and assuming an age limit of 20 years.

As far as PM_{10}, we can see that combined strategy eight would be able to achieve sustained emissions reductions when considering the changes presented in table 6-14.

Given the nonlinearities discussed earlier regarding the costs of fleet operational and utilization improvement strategies, determining the costs of these new combined strategies would present inaccuracies that cannot be avoided with the level of information currently available. However, in order to get an order of magnitude of their costs, we have estimated them given two assumptions. First, costs for fleet operational and utilization strategies when implemented together are additive. Second, these costs include only the cost of acquiring light-duty vehicles or renewing the fleet. Our results are shown in table 6-25.

Table 6-25 Total Costs of the MCMA Freight Fleet for Combined Strategies

Strategy	Present Value of Total Costs of the MCMA Freight Fleet (2000-2025) in BYBMXP[1/]		
	Divided City	Changing Climates	Growth Unbound
Base Case	749	925	1,356
6	783 (4.5%)	973 (5.2%)	1,422 (4.9%)
7	842 (12.4%)	1,052 (13.7%)	1,532 (13.0%)
8	863 (15.2%)	1,087 (17.5%)	1,574 (16.1%)

1/ Year 2000 Billion Mexican Pesos. The discount rates are: "Divided City" = 13%; "Changing Climates" = 10%; "Growth Unbound" = 8%.

Note: figures in parenthesis represent the percent increase in total costs with respect to the Base Case.

From table 6-25 we can see that costs would be considerably higher for combined strategies seven and eight. In fact, they could rise as much as 17% with respect to the base case. It is worth mentioning that these cost figures should be taken only as a first estimate of the real costs for the reasons mentioned earlier.

Our analysis of these three combined strategies so far includes an estimation of their capability of achieving substantial and sustained freight-related emissions reductions, as well as the costs of the MCMA freight fleet if they are implemented. We have also determined their performance with respect to changes in their implementation. Tables 6-26, 6-27 and 6-28 include a summary of each combined strategy's performance for all three pollutants analyzed[71].

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[71] In these tables we have not included the summary of each strategies' performance with respect to changes in their implementation due to space constraints. However, the reader could look at tables 6-15 to 6-24 to assess each strategies performance with respect to the implementation changes considered.

Table 6-26 Combined Vehicle Technology and Fuel Quality Improvement & Fleet Operational and Utilization Improvement Strategies' Performance for NMHC

Combined Strategies	Emissions Reductions with Respect to Base Case	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000	Percentage Increase of Total Costs with Respect to Base Case	Cost Effectiveness (tonnes/BYBMXP[1/])
6	4%	29%-101%	4.5%-5.2%	39-69
7	19%	8%-71%	12.4%-13.7%	172-289
8	44%-45%	(33%)-9%	15.2%-17.5%	402-666

1/ BYBMXP is equal to Year 2000 Billion Mexican Pesos.

Note: 1) figures in parenthesis represent negative values; 2) assuming 50% of all out of region heavy-duty vehicles would be kept out of the MCMA by establishing freight centers and/or increasing the railroad's utilization for transporting goods entering or leaving the MCMA.
3) assuming Logistics Companies would substitute 50% of the local fleet usage and 20% empty trip reduction.

From this table we can note that combined strategy eight would be capable of achieving substantial freight-related NMHC emissions reductions (up to 45% with respect to the base case); however, these emissions reductions would not be sustainable for all future stories because of the growth in freight traffic in the MCMA. Combined strategy eight would also be the most cost-effective, followed by combined strategy seven.

Table 6-27 Combined Vehicle Technology and Fuel Quality Improvement & Fleet Operational and Utilization Improvement Strategies' Performance for NO_x

Combined Strategies	Emissions Reductions with Respect to Base Case	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000	Percentage Increase of Total Costs with Respect to Base Case	Cost Effectiveness (tonnes/BYBMXP[1/])
6	8%-9%	31%-102%	4.5%-5.2%	56-100
7	30%-31%	(7%)-47%	12.4%-13.7%	191-316
8	41%	(30%)-11%	15.2%-17.5%	252-417

1/ BYBMXP is equal to Year 2000 Billion Mexican Pesos.

Note: 1) figures in parenthesis represent negative values; 2) assuming 50% of all out of region heavy-duty vehicles would be kept out of the MCMA by establishing freight centers and/or increasing the railroad's utilization for transporting goods entering or leaving the MCMA.
3) assuming Logistics Companies would substitute 50% of the local fleet usage and 20% empty trip reduction.

From this table we can note that combine strategies seven and eight would be capable of achieving substantial freight-related NO_x emissions reductions; however, they would not be substantial for all future stories considered due to the growth in freight traffic in the MCMA. Combined strategy eight would be the most cost-effective of these three combined strategies for NO_x.

Table 6-28 Combined Vehicle Technology and Fuel Quality Improvement & Fleet Operational and Utilization Improvement Strategies' Performance for PM_{10}

Combined Strategies	Emissions Reductions with Respect to Base Case	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000	Percentage Increase of Total Costs with Respect to Base Case	Cost Effectiveness (tonnes/BYBMXP[1/])
6	21%-24%	(3%)-41%	4.5%-5.2%	13-20
7	39%-44%	(68%)-(53%)	12.4%-13.7%	22-32
8	43%-47%	(70%)-(56%)	15.2%-17.5%	24-34

1/ BYBMXP is equal to Year 2000 Billion Mexican Pesos.

Note: 1) figures in parenthesis represent negative values; 2) assuming 50% of all out of region heavy-duty vehicles would be kept out of the MCMA by establishing freight centers and/or increasing the railroad's utilization for transporting goods entering or leaving the MCMA.
3) assuming Logistics Companies would substitute 50% of the local fleet usage and 20% empty trip reduction.

From this table we can note that all three combined strategies would be capable of achieving substantial freight-related PM_{10} emissions reductions. In fact, combined strategy eight could achieve up to a 47% reduction in freight-related PM_{10} emissions if implemented. Combined strategies seven and eight would be capable of achieving substantial emissions reductions, but would also have the highest increase in costs if implemented. Combined strategy eight would be the most cost-effective, followed closely by combined strategy seven.

6.4 Key Findings and Assessments

In this chapter we have estimated the impact of improving freight fleet operations on air quality. More specifically, we have estimated the amount of emissions reductions that could be achieved by keeping out of region heavy-duty vehicles from circulating in the MCMA and having light-duty vehicles making final deliveries or initial pick ups within the city. Likewise, we have estimated the impact of reducing local freight vehicles' empty trips as well as renewing the freight fleet.

We have presented and discussed three strategies that could improve freight fleet operations in the MCMA. The first of them includes the establishment of freight transfer centers in the outer limits of the MCMA. We have seen that such centers are currently operating in different urban areas around the world and present our vision of how they should operate in the MCMA. We also include a discussion regarding the increase of railroad utilization for goods transported into and out of the MCMA. We believe that current times present an opportunity to increase their utilization in the MCMA. More specifically, turning railroad terminals into intermodal terminals, in which value added services (i.e. warehouse management, freight consolidation, freight tracking through GPS) are offered could increase their utilization for transporting goods into and out of the MCMA.

In order to improve local freight fleet operations we have presented the creation of Logistics Companies that could carry out private companies' freight transportation requirement. These companies should not only offer transportation services, but also other value added services.

We have seen that these strategies would be capable of achieving substantial emissions reductions for key pollutants NMHC, NO_x and PM_{10}.

We also present three different combined strategies that include freight strategies from both categories 1) vehicle and fuel quality improvements and 2) fleet operational and utilization improvements. We have analyzed and estimated their capability of achieving substantial and sustained emissions reductions, as well as their robustness with respect to uncertainties posed by the Future Stories, as well as our assumptions and changes in their implementation. Our analysis shows that combined strategy eight would have the overall best performance; however, its costs would rise substantially with respect to the base case.

Similarly to the strategies presented in chapter five, these results must be presented to decision makers in the MCMA and discuss with them their priorities in terms of emissions' reductions for each pollutant.

In our next chapter we will present a summary of all strategies presented in Chapter Four, Five and Six. Their performance with respect to their capability of achieving substantial and sustained emissions reductions capability, as well as their robustness with respect to the uncertainties posed by the future stories and unforeseen changes in their implemented will be compared in order to determine the best overall strategies to be implemented in the MCMA.

CHAPTER 7: CONCLUSIONS

7.1 Key Findings

Our analysis of the current freight transportation system in the MCMA shows that the freight transportation's contribution to emissions of key pollutants, non-methane hydrocarbons (NMHC), nitrogen oxides (NOx) and particulate matter (PM10) is substantial. We have estimated that approximately 9%, 12% and 8% of all PM_{10}, NO_x and NMHC emissions in the MCMA are directly attributable to freight vehicles.

Freight transportation demand, measured in vehicle-km, will continue to grow considerably in the future. By year 2025, it could range between 13,000 million and 23,000 million vehicle-km depending on the future story considered.

This growth in freight traffic would cause a substantial growth in all pollutant emission levels. Freight NMHC emission levels could range by year 2025 between 50 and 80 ktonnes which would represent an increase between 40% and 110% increase with respect to year 2000 depending on the future story considered.

Freight NO_x emission levels could range by year 2025 between 45 and 55 ktonnes, an increase between 49% and 123% with respect to year 2000 depending on the future story considered.

Freight PM_{10} emission levels could range by year 2025 between 2.8 and 4.7 ktonnes, an increase between 73% and 149% with respect to year 2000 depending on the future story considered.

These increments in emissions call for the need to devise and implement freight-related strategies in the MCMA aimed towards reducing key pollutant emissions.

Throughout our analysis in this thesis, we have constructed and evaluated freight strategies to reduce emissions of key pollutants in the MCMA. Some of these strategies were originally proposed by the MCMA government officials[72]. We have seen that it is possible to use vehicle technology and fuel quality improvements to obtain substantial and sustained emissions reductions. Furthermore, by improving freight fleet operations in the MCMA, it could also be possible to obtain substantial and sustained freight emissions reductions for key pollutants.

Our analysis shows that the freight strategies proposed by the government would not be able to achieve substantial and sustained freight emissions reductions for key pollutants. However, one of them (implementation of stricter emission standards for new heavy-duty diesel vehicles) would be effective in reducing PM_{10} emissions.

The main reason behind the failure of freight strategies to achieve sustained emissions reductions is simply the increase of freight traffic in the MCMA, reflecting economic growth.

The eight vehicle technology and fuel quality improvement strategies presented and analyzed in Chapter Five would not be capable of achieving freight-related substantial and sustained emissions reductions of key pollutants under all future stories analyzed; however, when implemented together (combined strategies) it could be possible of achieving both substantial and sustained freight emissions reductions. In fact, the best performing combined strategy (combined strategy five)[73] could achieve up to 54%, 48% and 40% freight emissions reductions for NMHC, NO_x and PM_{10}, respectively with respect to the base case; however the costs associated with it would also be substantial (approximately 15% increase with respect to the base case).

We have also analyzed the impact on pollutant emissions of improving the freight fleet operations in the MCMA. Our analysis has focused on the out of region freight fleet and the local freight fleet. In Chapter Two we saw that heavy-duty gasoline and diesel vehicles have the highest emission rates of NMHC, NO_x and PM_{10}. Furthermore, we saw that the out of region freight fleet is composed mainly by these types of vehicles. Banning them from entering the MCMA would help improve air quality, but would also

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[72] They were elaborated by the Comision Ambiental Metropolitana (CAM)

[73] Includes 1)Stricter emission standards for new heavy-duty diesel vehicles; and 2) 15 year old age limit for heavy-duty diesel and gasoline vehicles and light-duty gasoline vehicles

have considerable negative impacts on the region by disrupting freight fleet operations in the MCMA. To overcome this negative impact we have proposed and analyzed the impact of the installation of freight transfer centers in the outer boundaries of the MCMA that could work as a liaison between heavy-duty vehicles circulating on highways and a series light-duty vehicles making deliveries or pick ups within the city. We have also analyzed the possibility of increasing the usage of the railroad for transporting goods entering or leaving the MCMA by transforming railroad terminals in the MCMA into intermodal terminals. Our analysis shows that both strategies could have a significant impact on freight PM_{10} and NO_x emissions, but not on freight NMHC emissions.

Operating inefficiencies in the local freight fleet[74], coupled with the level of service required by private companies have served as the main reasons behind the construction of a strategy aimed towards reducing the amount of freight vehicles' empty trips, as well as improving the services offered by public companies (for hire) offering transportation services. Such strategy relates to the creation of "Logistics Companies" which should not only provide efficient and reliable transportation services, but also other logistics-related services, such as warehouse and inventory management, product tracking, among others. Our analysis shows that this strategy could have a significant impact on freight NMHC and NO_x emissions, but not on freight PM_{10} emissions.

These fleet operational and utilization strategies could be applied simultaneously to take advantage of their individual capabilities of achieving emissions reductions. Our analysis shows that if implemented simultaneously, these strategies could potentially achieve substantial and sustained emissions reductions for all three key pollutants. Furthermore, these strategies would have other benefits associated with them, such as economic growth of the MCMA through the creation of jobs and improvement of trade between the MCMA and other regions.

Fleet operational and utilization strategies could also be coupled with vehicle technology and fuel quality improvement strategies. By doing this, we could combine the potential of both types of strategies to achieve substantial and sustained emissions reductions.

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[74] Approximately 30% of the total amount of freight vehicle trips are empty trips. SETRAVI (1996)

Our analysis shows that these combined strategies could be able to achieve both substantial and sustained freight emissions reductions. In fact, combined strategy eight[75] could achieve 45%, 41% and 47% of freight NMHC, NO_x and PM_{10} emissions reductions with respect to the base case; however, the costs associated with this combined strategy would also be substantial (approximately 16% with respect to the base case).

The strategies and combined strategies discussed in this thesis would have considerably high cost increments for the freight fleet in the MCMA. When analyzing and discussing their economical feasibility it is important to determine who will bear such cost increments. For instance, if the vehicle fleet is renewed by setting a maximum age limit, freight vehicle owners (i.e. private companies) would have to invest a considerable amount of money to comply with it. These companies might not have the necessary financial resources needed to renew their fleet or, if they do, they might transfer these costs increments to their customers; thus, the end customers would ultimately fund their fleet renewal. It could also be possible for the government to invest public funds and subsidize the cost increments posed by each strategy to be implemented. These strategies would improve the freight transportation system in the MCMA, which would be beneficial for its residents and companies located in it. A viable freight transportation system would help sustain the region's economic growth, while maintaining low negative effects, such as pollutant emissions. Therefore, since it is in the region's best interest to have a viable freight transportation system, these cost increments could also be met by both the public and private sectors. For instance, a program to finance the fleet renewal could be offered by the government to freight vehicle owners by which they are offered to low interest loans to purchase a new freight vehicle.

In Chapter Six we discussed the possibility of having joint public and private ventures when establishing freight transfer centers. Likewise, the public sector could also be involved in the development of intermodal terminals for railroads. Therefore, the costs of implementing either one of these strategies could be paid by the private or public sector solely or in conjunction. In fact, the government could provide the initial funds needed to

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[75] Includes 1) Stricter emission standards for new heavy-duty diesel vehicles; 2) 15 year old age limit for heavy-duty diesel and gasoline vehicles; 3) creation of logistics companies; 4) keeping out of region heavy-duty vehicles from circulating in the MCMA by establishing freight transfer centers or increasing railroad utilization; and 4) extra freight demand of light-duty vehicles met with light-duty natural gas vehicles

develop the freight transfer centers or construct the necessary facilities to transform railroad terminals into intermodal terminals and have the private sector bear the costs of purchasing the light-duty vehicles needed to make deliveries and pick ups within the MCMA. Such vehicles could be purchased with low interest loans provided by the government. The use of public funds to implement these strategies can be justified because they would improve the freight transportation system in the MCMA. In fact, they would help the MCMA have a viable freight transportation system, which is in the city's best interest. Furthermore, these strategies would have other economical benefits associated with them, i.e. economic growth of the region, through the creation of jobs and the improvement of trade between the region and other regions.

Our analysis throughout this thesis shows the capability of achieving substantial and sustained emissions reductions under all future stories considered. Furthermore, their performance with respect to changes in their implementation has also been analyzed and discussed. These strategies should be presented to decision-makers in the MCMA in order to discuss their economical and political feasibility.

A summary of the main results of our analysis of the strategies presented are shown in tables 7-1, 7-2 and 7-3. Strategies one through eight are explained in detail in Chapter Five. Likewise, combined strategies one through five are also explained in Chapter Five. Strategies six through eight, as well as combined strategies six through eight are explained in detail in Chapter Six.

Table 7-1 Freight Strategies Performance for NMHC

Strategy	Emissions Reductions with Respect to Base Case	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000	Percentage Increase of Total Costs with Respect to Base Case	Cost Effectiveness (tonnes/BYBMXP$^{1/}$)
1	1%	32%-106%	0.2%-0.3%	10-13
2	5%	29%-101%	7.2%-7.7%	45-77
3	34%-35%	(35%)-7%	3.4%-3.8%	353-572
4	12%	25%-96%	4.3%-4.6%	115-201
5	2%-3%	35%-110%	10.0%-10.5%	22-42
6	5%	34%-109%	7.5%-7.8%	45-83
7	5%-6%	30%-103%	0.6%-0.8%	56-91
8	25%-29%	12%-64%	6.4%-6.7%	247-473
Combined Strategy				
1	7%	17%-83%	7.4%-7.8%	72-116
2	35%-39%	(9%)-51%	6.1%-6.6%	343-634
3	46%-47%	(46%)-(11%)	7.5%-8.4%	451-743
4	44%-49%	(30%)-(5%)	11.9%-13.9%	412-739
5	53%-54%	(65%)-(40%)	14.8%-16.2%	489-803
6	4%	29%-101%	4.5%-5.2%	39-69
7	19%	8%-71%	12.4%-13.7%	172-289
8	44%-45%	(33%)-9%	15.2%-17.5%	402-666

1/ BYBMXP is equal to Year 2000 Billion Mexican Pesos.
Note: figures in parenthesis represent negative values

Combined strategy five, would have the highest cost-effectiveness for NMHC, followed by combined strategies three, four, eight and two, respectively

Table 7-2 Freight Strategies Performance for NO_x

Strategy	Emissions Reductions with Respect to Base Case	Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000	Percentage Increase of Total Costs with Respect to Base Case	Cost Effectiveness (tonnes/BYBMXP[1/])
1	1%	39%-115%	0.2%-0.3%	10-13
2	21%-22%	15%-80%	7.2%-7.7%	138-237
3	16%-17%	(2%)-53%	3.4%-3.8%	121-183
4	6%	39%-115%	4.3%-4.6%	40-67
5	11%-13%	36%-113%	10.0%-10.5%	72-140
6	1%	46%-126%	7.5%-7.8%	5-11
7	1%	43%-122%	0.6%-0.8%	10-17
8	11%-13%	25%-97%	6.4%-6.7%	73-141
Combined Strategy				
1	24%-25%	(6%)-48%	7.4%-7.8%	165-275
2	16%-18%	20%-90%	6.1%-6.6%	108-197
3	22%-23%	(9%)-43%	7.5%-8.4%	155-240
4	41%-44%	(33%)-11%	11.9%-13.9%	266-455
5	47%-48%	(60%)-(34%)	14.8%-16.2%	300-481
6	8%-9%	31%-102%	4.5%-5.2%	56-100
7	30%-31%	(7%)-47%	12.4%-13.7%	191-316
8	41%	(30%)-11%	15.2%-17.5%	252-417

1/ BYBMXP is equal to Year 2000 Billion Mexican Pesos.
Note: figures in parenthesis represent negative values

Combined strategy five would have the highest cost-effectiveness for NOx, followed by combined strategies four and eight, respectively.

Table 7-3 Freight Strategies Performance for PM_{10}

Strategy	**Emissions Reductions with Respect to Base Case**	**Percentage Increase/ (Decrease) of Year 2025 Emission Levels with Respect to Year 2000**	**Percentage Increase of Total Costs with Respect to Base Case**	**Cost Effectiveness (tonnes/BYBMXP[1/])**
1	10%-13%	16%-70%	0.2%-0.3%	7-9
2	4%-5%	64%-147%	7.2%-7.7%	2-4
3	0%	68%-151%	3.4%-3.8%	0
4	0%-1%	68%-151%	4.3%-4.6%	0-1
5	1%-2%	72%-157%	10.0%-10.5%	1
6	0%	69%-153%	7.5%-7.8%	0
7	12%-13%	36%-107%	0.6%-0.8%	7-10
8	1%-2%	67%-151%	6.4%-6.7%	1
Combined Strategy				
1	34%-37%	(77%)-(66%)	7.4%-7.8%	20-30
2	1%-3%	66%-149%	6.1%-6.6%	1
3	1%-2%	67%-150%	7.5%-8.4%	1
4	36%-40%	(80%)-(70%)	11.9%-13.9%	20-30
5	36%-40%	(79%)-(69%)	14.8%-16.2%	20-30
6	21%-24%	(3%)-41%	4.5%-5.2%	13-20
7	39%-44%	(68%)-(53%)	12.4%-13.7%	22-32
8	43%-47%	(70%)-(56%)	15.2%-17.5%	24-34

1/ BYBMXP is equal to Year 2000 Billion Mexican Pesos.
Note: figures in parenthesis represent negative values

Combined strategy eight would have the highest cost-effectiveness for PM_{10}, followed by combined strategies seven, five, four, one and six, respectively.

7.2 Key Uncertainties

Throughout our analysis we have had to deal with multiple sources of uncertainty. The main sources of uncertainty and our handling of them are the following:

1) *Uncertainties with respect to the future development of the MCMA.* We handle this type of uncertainty through the creation of the future stories. By evaluating all strategies

under all future stories created helps us better plan under the presence of uncertainty posed by the driving forces included in them (e.g. economy, population).

2) Uncertainties with respect to assumptions made in the modeling process. We handle this type of uncertainties in two different ways. First, the creation of the future stories helps us deal with some of the assumptions made in the modeling process. For instance, the relationship between freight transportation demand growth and population growth might not be precisely the one we use in our analysis; however, by having three different future stories, and consequently, three different estimates of future freight transportation demand, we can better plan than if planning under only one future development of the MCMA.

Second, we can estimate the sensitivity of our assumptions we can better understand their consequences on our analysis. For instance, in Chapter Six we saw that the equivalent number of vehicle-km of light-duty vehicles needed to replace the heavy-duty vehicles that would be kept out of the MCMA might not be what we originally estimated; however, after testing different estimates of the equivalent vehicle-km (100% higher and lower than our original estimate) needed we saw that our conclusions would not change with respect to NO_x and PM_{10} emissions.

3) Uncertainties with respect to technological innovation and the rate of technological absorption in the MCMA. The uncertainty with respect to technological innovation is handled by analyzing what are driving forces behind such innovation. Our analysis shows that the rate of technological adoption in the MCMA is driven mainly by government regulations. Therefore, we assumed that major technological improvements (in terms of fuel efficiency and emissions rates) would occur only if regulations are enforced.

The rate of technological absorption in the MCMA is included within the strategies analyzed. For instance, the enforcement of stricter emission standards for new heavy-duty diesel vehicles includes a deployment schedule describing the rate at which these stricter emissions standards would be applied in the MCMA. This deployment schedule could be viewed as a proxy for the rate of technological absorption in the MCMA. Thus, by testing different deployment schedules, as we do in chapters four, five and six, we can evaluate the impact of having different technology absorption rates.

4) Uncertainty with respect to the implementation of strategies. As discussed in earlier chapters, this uncertainty is particularly relevant for the MCMA given its political structure. The implementation of all the strategies analyzed requires coordination between the governments of the Distrito Federal (DF), the Estado de Mexico (EM) and the Federal Government. Therefore, it is reasonable to believe that any strategy might not be implemented as originally planned. To deal with this type of uncertainty we analyze each strategy's performance with respect to changes in their rate of implementation. We evaluate their capability of achieving substantial and sustained emissions reductions if they are not implemented as originally planned.

We believe that these main sources of uncertainty are addressed properly throughout our analysis. Therefore, from our analysis of the freight strategies and combined strategies decision-makers can see each not only each strategy's capability of achieving substantial and sustained emissions reductions, but also their robustness with respect to the uncertainties described above.

In this thesis we have presented eight strategies and eight combined strategies. Their capability of achieving substantial and sustained emissions reductions for key pollutants has been analyzed. Furthermore, their performance with respect to different levels of uncertainty (e.g. uncertainty posed by the future stories and with respect to changes in their implementation) has been estimated. The analysis and results presented could be used by decision-makers to improve the freight transportation system in the MCMA. Based on our analysis decision-makers can judge what type of pollutant emissions they wish to reduce and better understand what strategies should be implemented in the MCMA, as well as their performance with respect to the uncertainties presented earlier. Therefore, if implemented, they could help achieve a viable freight transportation system in the MCMA to support its economic growth.

7.3 Next Steps

7.3.1 Improvements in our Analysis

Our analysis shows that the fleet operational and utilization improvement strategies presented in this thesis could potentially achieve substantial and sustained emissions reductions for all three key pollutants. However, this analysis should be seen as a first estimate of their potential benefits. As mentioned in Chapter Six, there are still issues related to their level of acceptance (i.e. number of heavy-duty vehicles that will use the freight transfer centers), as well as the costs associated with them that need to be analyzed more detailed. We were unable to do this because we lacked the data needed to perform such an analysis. It is our belief that it could be possible to build upon our analysis of these strategies to carry out more detailed analyses. Such analyses could start with the recollection of data regarding private companies in the MCMA, their freight transportation needs, as well as the services offered by freight transportation companies in the region.

In our analysis we have not included the impact on congestion of the strategies analyzed. We believe that if congestion is included, the fleet operational and utilization improvement strategies would most likely be capable of achieving higher emissions reductions than the ones presented here.

7.3.2 Areas of Future Research

In this thesis we have focused on two types of strategies to reduce emissions related to freight transportation: 1) vehicle technology and fuel quality improvements; and 2) fleet operational and utilization improvements. However, emissions reductions could also be achieved by applying pricing mechanisms such as congestion pricing. The basic idea behind congestion pricing is to charge different vehicles, including freight vehicles, a fare to be allowed to use the road network, or a part of it, during certain time of the day.

There are different criteria that can be used to set the price vehicle drivers would have to pay to be allowed to use the road network. Among them there is their willingness to pay and the externalities caused by their vehicles. The externalities caused by vehicles depend not only on the vehicle entering the network, but also on the current status of the network and the region; i.e. vehicle flow conditions, pollutant emission levels, etc.

Simply stated, the congestion pricing problem could be summarized as the following question: how can we manage the city's roadway in order to improve its operations and reduce emissions reductions using congestion pricing as a tool? In other words, we can treat the roadway capacity as a resource which could be managed using pricing policies in the most effective way in order to achieve a certain goal, which could be the minimization of externalities caused by its users, the maximization of vehicle flows through the network, among others.

By looking back in the literature, we can see that this general problem has been studied before under different settings. For instance, many companies deal with the problem of managing a fixed capacity which must be allocated to different customers in the most effective way in order to maximize their profit. Companies have used price as a tool to achieve this because it is one of the most effect variables that managers can manipulate to manage demand.

Companies in different industries have used the principles of Yield Management to improve their operations and increase their revenues. The basic function of Yield Management is the management of the capacity and price of a perishable asset which will be used by or sold to a demand which is both stochastic and price sensitive. There are examples that illustrate the effectiveness of revenue management tools in the improvement of companies' operations; among them is the success in the airline industry. Likewise, Yield Management has been applied successfully in sectors other than the airline sector; such as automobile rental, cruise lines, lodging and hotels, passenger railways, among others.

By comparing the Yield Management problem and the congestion problem, we can see that the basic idea behind both of them is the same: the management of a perishable asset (road network) and its price (congestion pricing) to serve a demand (vehicles, including freight vehicles) which is both stochastic and price sensitive.

According to Weatherford and Bodily (1992), there are three common characteristics that are common to all Yield Management problems:

1. Perishability: one date on which the product or service becomes available and after which it is either not available or it ages. In other words, the product or service cannot be stored.
2. Fixed Capacity: more precisely a high cost of adding an incremental unit of capacity.
3. Ability to segment customers: the characteristic used to segment the market must truly differentiate the product or service offered. For example, in the case of airlines, customers are segmented into business and leisure passengers using restrictions such as mandatory Saturday night stayover and making tickets nonrefundable in event of cancellations.

A careful analysis shows that these three characteristics are applicable in Congestion Pricing problem as well.

Perishability: if we consider the road network's capacity as the resource, it will certainly be considered perishable in the sense that capacity not used today cannot be stored and used tomorrow.

Fixed Capacity: even though road capacity can be added to the network, this would take a considerable amount of time. Since congestion pricing decisions will be taken in a relatively short-term time frame, we can safely consider capacity to be fixed.

Ability to segment customers: the customers in this case can be segmented using different criterions. The first could be by vehicle type, i.e. private autos, buses, trucks, etc. This segmentation allows us to determine the resource requirements for each type, the burden they cause to the system and its users, their demand pattern, etc. Customers could further be segmented into different categories according to their price sensitiveness.

This preliminary discussion indicates that in principle the congestion pricing problem could be formulated as a yield management problem, which in turn could help achieve emissions reductions in the MCMA. Most importantly, it could help in the creation of a viable freight transportation system for the MCMA needed to sustain economic growth in the region.

7.4 A Final Word

The author hopes that this thesis is of use to the reader by illustrating and exploring different alternatives to reduce the negative impact of freight transportation in an urban area without hindering its economic growth. It is our desire that the analysis and results presented in this thesis can be used by decision-makers towards creating a viable freight transportation system in the Mexico City Metropolitan Area.

APPENDIX: NUMERICAL VALUES OF MAIN MODELING ASSUMPTIONS

Fleet Composition for Each Future Story (%)

Vehicle Type	Future Stories		
	Divided City	Changing Climates	Growth Unbound
Light-Duty Gasoline	60%	65%	55%
Light-Duty Natural Gas	4%	5%	5%
Heavy-Duty Gasoline	19%	15%	20%
Heavy-Duty Diesel	17%	15%	20%
Total	**100%**	**100%**	**100%**

Annual Vehicle Utilization (annual km)

Vehicle Type	Future Stories		
	Divided City	Changing Climates	Growth Unbound
Light-Duty Gasoline	15,600	11,700	14,300
Light-Duty Natural Gas	15,600	11,700	14,300
Heavy-Duty Gasoline	15,600	11,700	14,300
Heavy-Duty Diesel	14,300	9,100	11,700

Vehicle Fuel Efficiency (miles/gallon)

Model Year	Vehicle Type		
	Light-Duty Gasoline	Heavy-Duty Gasoline	Heavy-Duty Diesel
Pre 1973	10.64	7.88	5.04
1973	10.45	7.9	5.10
1974	10.45	8.06	5.14
1975	11.45	8.22	5.18
1976	12.05	8.46	5.22
1977	13.09	8.68	5.26
1978	12.78	8.87	5.30
1979	12.31	9.01	5.10
1980	15.3	9.56	5.20
1981	16.43	9.73	5.30
1982	16.77	10.07	5.50
1983	17.31	10.13	5.60
1984	17.02	10.15	5.60
1985	17.16	10.05	5.70

1986	17.88	10.22	5.80
1987	18.05	10.25	5.80
1988	17.58	10.27	5.80
1989	17.28	10.27	5.70
1990	17.29	10.2	5.80
1991	17.1	10.48	5.80
1992	17.05	10.49	5.80
1993	16.99	10.5	5.80
1994	16.93	10.51	5.90
1995	16.87	10.52	6.10
1996	16.87	10.52	5.10
1997	16.87	10.53	5.10
1998	16.87	10.53	5.10
1999	16.86	10.53	5.10
2000	16.86	10.53	5.10

Average annual inflation for each future story:
Divided City: 6%
Changing Climates: 5%
Growth Unbound: 7%

Energy Costs for Future Story "A Divided City"

	Gasoline "Magna" (MXP/liter)	Gasoline "Premium" (MXP/liter)	Diesel 500 ppm (MXP/liter)	Diesel 30 ppm (MXP/liter)	Natural Gas (MXP/m^3)
2000	5.3	5.95	4.39	4.31	3.093
2001	5.61	6.29	4.65	4.57	1.327
2002	5.8	6.5	4.81	4.73	0.895
2003	4.16	4.67	3.44	3.38	0.70
2004	4.49	5.04	3.72	3.65	0.76
2005	4.79	5.38	3.97	3.90	0.81
2006	5.10	5.72	4.22	4.15	0.86
2007	5.56	6.24	4.60	4.52	0.94
2008	6.03	6.77	5.00	4.91	1.02
2009	6.49	7.28	5.37	5.28	1.10
2010	6.95	7.80	5.75	5.65	1.17
2011	7.44	8.35	6.16	6.05	1.26
2012	8.08	9.07	6.69	6.57	1.36
2013	8.65	9.71	7.17	7.03	1.46
2014	9.31	10.46	7.72	7.57	1.57
2015	9.99	11.21	8.27	8.12	1.69
2016	10.79	12.11	8.93	8.77	1.82
2017	11.55	12.96	9.57	9.39	1.95
2018	12.42	13.94	10.28	10.10	2.10

2019	13.25	14.87	10.97	10.77	2.24
2020	14.13	15.87	11.71	11.49	2.39
2021	15.11	16.96	12.51	12.29	2.55
2022	16.18	18.17	13.41	13.16	2.73
2023	17.24	19.35	14.28	14.02	2.91
2024	18.42	20.68	15.26	14.98	3.11
2025	19.62	22.02	16.25	15.95	3.31

Energy Costs for Future Story “Changing Climates”

	Gasoline “Magna” (MXP/liter)	**Gasoline “Premium” (MXP/liter)**	**Diesel 500 ppm (MXP/liter)**	**Diesel 30 ppm (MXP/liter)**	**Natural Gas (MXP/m^3)**
2000	5.3	5.95	4.39	4.31	3.093
2001	5.61	6.29	4.65	4.57	1.327
2002	5.8	6.5	4.81	4.73	0.895
2003	5.76	6.46	4.77	4.68	0.97
2004	6.10	6.84	5.05	4.96	1.03
2005	6.41	7.20	5.31	5.22	1.08
2006	6.72	7.55	5.57	5.47	1.13
2007	7.01	7.86	5.80	5.70	1.18
2008	7.34	8.24	6.08	5.97	1.24
2009	7.66	8.60	6.35	6.23	1.29
2010	7.98	8.96	6.61	6.49	1.35
2011	8.32	9.34	6.89	6.77	1.40
2012	8.73	9.80	7.23	7.10	1.47
2013	9.10	10.22	7.54	7.40	1.54
2014	9.49	10.65	7.86	7.71	1.60
2015	9.90	11.12	8.20	8.05	1.67
2016	10.31	11.58	8.54	8.39	1.74
2017	10.77	12.09	8.92	8.76	1.82
2018	11.17	12.54	9.25	9.08	1.89
2019	11.62	13.04	9.62	9.45	1.96
2020	12.06	13.54	9.99	9.81	2.04
2021	12.55	14.08	10.39	10.20	2.12
2022	13.00	14.60	10.77	10.57	2.20
2023	13.59	15.26	11.26	11.06	2.30
2024	14.20	15.94	11.76	11.55	2.40
2025	14.81	16.63	12.27	12.04	2.50

Energy Costs for Future Story "Growth Unbound"

	Gasoline "Magna" (MXP/liter)	Gasoline "Premium" (MXP/liter)	Diesel 500 ppm (MXP/liter)	Diesel 30 ppm (MXP/liter)	Natural Gas (MXP/m^3)
2000	5.3	5.95	4.39	4.31	3.093
2001	5.61	6.29	4.65	4.57	1.327
2002	5.8	6.5	4.81	4.73	0.895
2003	6.30	7.07	5.22	5.12	1.06
2004	6.64	7.46	5.50	5.40	1.12
2005	7.00	7.86	5.80	5.69	1.18
2006	7.38	8.29	6.11	6.00	1.25
2007	7.66	8.60	6.34	6.23	1.29
2008	7.99	8.97	6.62	6.50	1.35
2009	8.35	9.37	6.92	6.79	1.41
2010	8.71	9.78	7.22	7.09	1.47
2011	9.03	10.14	7.48	7.34	1.52
2012	9.43	10.59	7.81	7.67	1.59
2013	9.82	11.02	8.13	7.99	1.66
2014	10.22	11.47	8.46	8.31	1.73
2015	10.61	11.91	8.79	8.63	1.79
2016	11.02	12.38	9.13	8.96	1.86
2017	11.49	12.90	9.52	9.35	1.94
2018	11.95	13.41	9.90	9.72	2.02
2019	12.46	13.98	10.32	10.13	2.10
2020	12.96	14.55	10.74	10.54	2.19
2021	13.45	15.10	11.14	10.94	2.27
2022	13.97	15.69	11.57	11.36	2.36
2023	14.57	16.35	12.06	11.84	2.46
2024	15.15	17.00	12.55	12.32	2.56
2025	15.75	17.68	13.04	12.81	2.66

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