The Benefits and Costs of a Bus Rapid Transit System in Mexico City

Final Report

Instituto Nacional de Ecología

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Acknowledgements

This study was coordinated by the Instituto Nacional de Ecología (INE) in Mexico City. Gretchen Stevens prepared the final report. The study was designed by Miriam Zuk, Leonora Rojas and Rodolfo Iniestra. The methods used in this report were developed by Gretchen Stevens and Miriam Zuk. Rodolfo Iniestra, Angélica Velázquez, and Porfirio Franco developed the emissions factors and wrote Appendix 2. The travel demand model presented in Appendix 1 was adapted by Angélica Velázquez and Julia Gamas. Finally, Gretchen Stevens developed the methods for evaluation of health benefits presented in Appendix 2.

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I. Executive Summary

A bus rapid transit system is a bus route that operates in a dedicated lane, where passengers pay prior to boarding at boarding stations. Bus rapid transit systems can provide a number of environmental, economic, and social benefits in cities where they are implemented. In order to promote the use of bus rapid transit systems in Mexico City, this analysis quantifies the most important environmental and economic benefits of a bus rapid transit corridor in Mexico City, called Metrobús. Metrobús began operation on Insurgentes Avenue in July, 2005.

Three benefits of Metrobús are quantified: the reduction in local emissions and resultant health impacts, the reduction in greenhouse gas emissions, and the reduction in travel time along Insurgentes during peak hours. To calculate these benefits, an empirical method is used to quantify changes in vehicle number and speeds along Insurgentes Avenue. The analysis is confined to the change in costs, emissions, and travel times on new articulated buses, as compared to the costs, emissions, and travel time on the buses, microbuses, and private vehicles they replaced. This method does not take into account any other changes in private vehicular traffic.

Between 2005 and 2015, it is estimated that the Metrobús corridor will reduce on average 144 tons of total hydrocarbons, 690 tons of oxides of nitrogen, 2.8 tons of fine particulate matter, and 1.3 tons of sulfur dioxide annually. These emissions reductions avoid an average of 6100 work loss days, 660 restricted activity days, 12 new cases of chronic bronchitis, and 3 deaths annually. These health improvements are estimated to result in $3 million (U.S. dollars) in health benefits each year.

Over the same 10-year period, the Metrobús corridor on Insurgentes is expected to eliminate 280,000 tons of carbon dioxide-equivalent emissions. We do not attach a monetary value to this emissions reduction because of the difficulty in estimating the social benefit of reducing greenhouse gas emissions.

The reduction in travel time for Metrobús users, based on travel time data for Insurgentes corridor during peak hours before and after Metrobús implementation, is statistically significant. We estimate that commuters using public transportation on Insurgentes Avenue during peak hours save over 2 million hours in travel time per year, which has an economic value of $1.3 million (U.S. dollars).

The cost of the Metrobús infrastructure, new vehicles, publicity, and fuel use are quantified. The Metrobús corridor had a social cost of over $44 million U.S. dollars in 2005, but it will represent a cost savings of over $3 million U.S. dollars annually from 2006 to 2015.

Taking into account the health benefits, travel time benefits, and costs of Metrobús, the system provides net benefits, with a net present value of $12.3 million U.S. dollars, using a discount rate of 7%. Results are robust to changes in underlying assumptions. Because a system of corridors would provide synergistic benefits, we expect that per-kilometer or per-line net benefits will be higher when Metrobús expands to other areas in Mexico City.

II. Introduction

The main objective of the Integrated Environmental Strategies (IES) program of the US Environmental Protection Agency, which is managed by the National Renewable Energy Laboratory, is to provide assistance to developing countries to identify and implement harmonized technology and policy measures to achieve local public health, economic, and environmental objectives in addition to significant greenhouse gas (GHG) reductions. In pursuing this objective, IES builds support and in-country capacity for the analysis and quantification of multiple benefits from integrated environmental policies.

The IES - Mexico project has focused on identifying key measures from the PROAIRE (Mexico City's air quality management plan), in addition to certain GHG control measures, and quantifying their impacts on local air quality and GHG reductions. The aim of the work is to encourage policy makers to simultaneously consider both local air quality and GHG goals. Two phases of the Mexico- IES project have been completed. Results from the first 'co-control' phase of the project, led by Dr. Jason West, demonstrated that the implementation of PROAIRE measures would reduce GHG emissions by over 3.1% in the year 2010. The second 'co-benefits' phase of the project, led by Dr. Galen McKinley, aimed to determine the local health benefits of air pollution controls while identifying their GHG reductions. In the second phase, it was determined that with five key control measures, over 4400 quality-adjusted life-years could be saved annually, in addition to a reduction of 1.5Mtons of GHGs per year.

The results of the first two phases of the IES-Mexico project have indicated that transportation measures have the largest potential for joint local/global benefits. In June of 2005, a bus rapid transit (BRT) route, called Metrobús, began operation on Insurgentes Avenue, a busy trunk road in Mexico City. A bus rapid transit system is characterized by dedicated bus lanes and boarding stations where passengers pay fares prior to boarding the bus. These two elements allow buses to travel at a higher average speed than traditional bus systems, as buses are not affected by traffic and transfer times at stops are low. The concept has generated a significant amount of interest among transportation professionals with the introduction of a highly successful BRT system in Bogotá, Colombia. If the Metrobús is successful, city officials have indicated plans to expand the Metrobús into a system of thirty-three corridors throughout the metropolitan area. In order to document the potential local and global benefits of this public transportation option, the objective of the third phase of the Mexico-IES Project is to conduct a detailed analysis of the health benefits and the costs of a bus rapid transit system in Mexico City.

III. Methods

In this phase of the Mexico-IES project, we perform a cost-benefit analysis of the Metrobús system that currently operates on Insurgentes Avenue. In order to compare the benefits - which are economic, social, and environmental - to the costs, benefits are expressed in monetary terms. We take a societal perspective when calculating costs and benefits; that is, we consider all costs and benefits without considering who is the payer or beneficiary. Under this perspective, transfers like taxes or interest are not included in the cost-benefit calculation, because the cost to the payer is equal to the benefit to the recipient, with a nil net cost to society.

In contrast, payments for labor or capital goods reflect the cost of resources that can no longer be used for another purpose.

A bus rapid transit system can provide a number of benefits to a diverse set of local and global stakeholders, from reduced greenhouse gas emissions to increasing social cohesion (Table 3.1). Some of these benefits have a larger economic value than others, and some can be translated into monetary terms more easily than others. Because this analysis is a continuation of prior co-benefits projects funded by the IES program, the original scope of the analysis was limited to calculating the local and global emissions benefits. However, we choose to also estimate time saved because we expect it will contribute an important portion of total benefits. Thus, in this analysis the following benefits are quantified:

- Reduction in greenhouse gas emissions
- Reduction in local emissions and health impacts
- Reduction in travel time during peak hours

Other benefits in Table 3.1 may also be important contributors to total benefits of the Metrobús system; however, it is out of the scope of the current analysis to attempt to quantify all benefits that may result from the system.

Table 3.1. Social benefits of a bus rapid transit system [1].

Category	**Description**
Economic	Reduced travel times
	More reliable product deliveries
	Increased economic productivity
	Increased employment
	Improved work conditions
Social	More equitable access throughout the city
	Reduced accidents and injuries
	Increased civic pride and sense of community
Environmental	Reduced emissions of air pollutants
	Reduced noise
Urban Form	More sustainable urban form, including densification along major corridors
	Reduced cost of delivering services such as electricity, water and sanitation

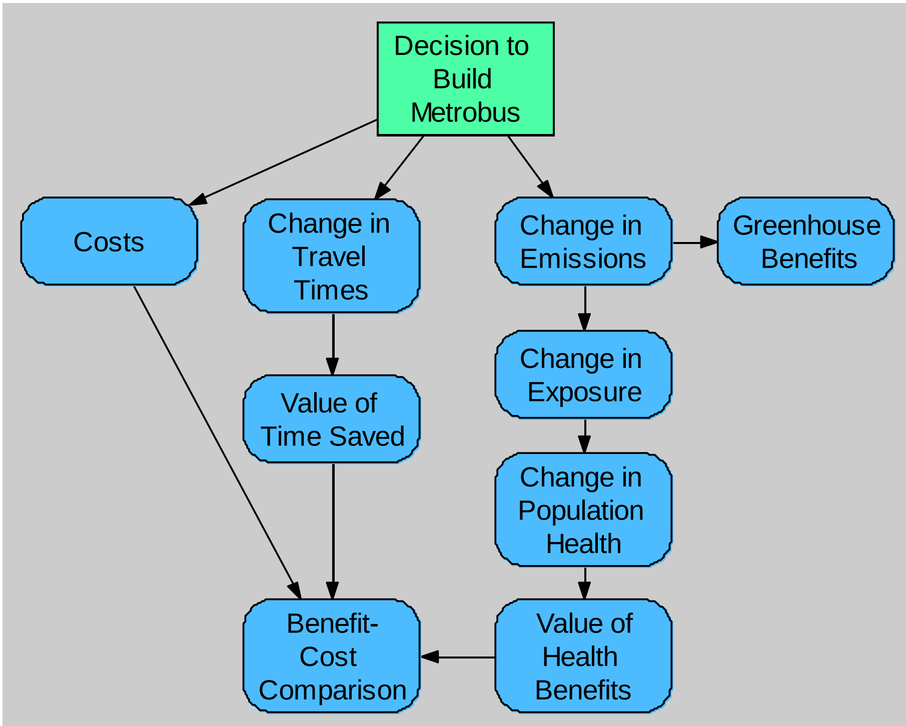

Figure 3.1. The analysis framework developed for this study.

The analysis framework used for this study is presented in Figure 3.1. First, the project and its ramifications to be analyzed are defined. In this case, the project is the Metrobús corridor on Insurgentes Avenue. In this analysis, the only ramifications of the project that are considered are the direct impacts of the technology change. The change in vehicle kilometers traveled, vehicle speeds, and fuel use are quantified (section 4). Then, the emissions reduction (section 5), the change in travel times (section 7), and the costs of the project (section 9) are calculated. Emissions reduction is an input to calculate change in concentration of a harmful air pollutant, which in turn is an input to calculate changes in health impacts (section 6). The economic value of the change in travel time is calculated (section 7). Finally, the economic benefits of the health impacts are calculated and compared to the costs of the measure (section 10). In addition, non-monetary greenhouse benefits are calculated (section 8).

Travel Demand Method

In order to quantify changes in emissions and travel times, researchers at the National Institute of Ecology (INE) obtained and modified a travel-demand model for Mexico City using the program Tranus (referred to as the travel demand method). This program has been widely used internationally in the integrated analysis of land use and transport for urban and regional scales. The Tranus model simulates the probable effects of urban and regional projects and policies, evaluated from social and energetic points of view. The city government hired ETEISA, a private consulting firm to develop a travel demand model for Mexico City using the program Tranus, in order to evaluate the impacts of a BRT corridor on the road Eje 8 Sur. ETEISA created a model of the Mexico City metropolitan area using data from a comprehensive 1994 origin-destination survey carried out by National Statistics and Geography Institute (INEGI) and from smaller-scale survey data taken in 2003 [2]. The model developed by ETEISA was subsequently modified by researchers at INE to model the impact of introducing a system of 33 corridors extending throughout the metropolitan area [3].

A model like Tranus makes many assumptions about behavior in order to estimate the impact of introducing confined corridors in Mexico City. These assumptions, many of which cannot be tested, increase the uncertainty around the primary analysis. A report by Rogers (2005) argues that the model developed by ETEISA was inadequate because the uncertainty about the emissions difference between the two scenarios (with and without the corridor) is greater than the estimated difference, *i.e.*, confidence intervals around the change in emissions include zero [4]. Given the criticisms of the model, INE hired an external consultant, Dr. Julia Gamas, to review and evaluate Tranus. Dr. Gamas made some improvements to the model and was able to replicate observed vehicle counts in the year 2003 [5]. However, Dr. Gamas concluded that that the model was not adequately calibrated to allow for projections of changes in consumer preferences, as is necessary for this analysis. Dr. Gamas' primary concerns included: 1) secondary roads were not considered, 2) taxis and informal public transportation were not included, and 3) additional sensitivity analyses were needed for several undocumented variables, including the values that indicate preferences for different types of transportation. Because of the limitations of the travel demand model, we do not use this method for our primary analysis. Costs and benefits calculated using the travel demand method are explored, however, in Appendix 1.

Empirical Method

In this analysis we present primary results using an empirical method that relies principally on measured values. In order to apply for Clean Development Mechanism (CDM) funds for the Metrobús project, the city government has measured many variables related to vehicle activity along the Insurgentes corridor prior to the construction of the Metrobús corridor [4, 6]. The values were reported in the Project Design Document (PDD) used to apply for CDM funds (referred to as the CDM document in this report) [6]. Using these values and data from the Metrobús operators and from other sources, we calculate the change in emissions that results from the change in public transportation technology used in the Insurgentes corridor.

The empirical method aims to calculate the difference between the actual situation on Insurgentes (the Metrobús scenario) and a counterfactual business-as-usual scenario (the baseline scenario). The baseline scenario is described using data on vehicle activities and speeds prior to the construction of the Metrobús corridor from data collected in 2004. The Metrobús scenario is described using data on vehicle activity and speeds collected after Metrobús began functioning. The most recent data available were used.

It is likely that, with an increasing vehicle fleet, the average speed on Insurgentes under the baseline situation would have deteriorated since 2004 and will continue to deteriorate in the near future. However, the activity of the Metrobús (in its confined corridor) shows very little variability, and is not projected to change significantly in the short term. Therefore, comparing the current activity levels of the Metrobús to the activity of the microbuses and buses that it replaced in 2004 is conservative, and becomes even more so when projected for future years.

Nevertheless, we use the calculated emissions difference for the first 10 years of operation, from 2005 to 2015. Benefits are considered to begin on July 1, 2005, so benefits for 2005 are only half the benefits for other years.

We only quantify changes in vehicular activity that can be characterized with measured values. Due to the limited empirical data, we confine this analysis to the direct impact of the new articulated buses on emissions, costs, and travel time of its users, compared to the emissions, costs, and travel time on the buses, microbuses, and private vehicles that they replace. This method does not take into account other changes private vehicular traffic, for which measured change in fuel economy or emissions are not available.

The CDM document, which makes a more comprehensive (though still incomplete) estimate of the greenhouse gas benefits of the Insurgentes corridor, predicted that the change in bus technology and modal shift provide only 54% of the total greenhouse benefits of the corridor [6]. The remaining benefits are derived from the improved operating conditions for other vehicles using Insurgentes. Therefore, the empirical method likely underestimates the total benefits of the Insurgentes corridor. Nevertheless, we chose not to include improved operating conditions as a benefit because measured average vehicle fuel economy on Insurgentes after the implementation of Metrobús is not available. The impact of this omission is characterized in the sensitivity analysis.

The greenhouse gas impact of increased traffic during the construction of the corridor was also evaluated in the CDM document [6]. The authors found that increased emissions were not significant compared to the emissions benefits during the same year. For that reason, they are not considered in this analysis.

IV. Change in Vehicle Activity

Three variables related to vehicle activity are quantified in this section: total vehicle kilometers traveled per year, total fuel used per year, and average vehicle speed. These three outputs are used to calculate changes in costs, emissions, and travel times. For each scenario, the following data are needed to calculate the change in vehicle activity:

- Number of articulated buses, or number of buses, microbuses and private vehicles replaced by articulated buses
- Average number of kilometers per day by vehicle type
- Average traveling speed
- Average fuel economy

In this section, we first discuss the activity of buses and microbuses in the baseline scenario. Then, we discuss the mode change: the private vehicles that are present in the baseline scenario, but are eliminated in the Metrobús scenario. Finally, we discuss the activity of the articulated buses in the Metrobús scenario.

Baseline Scenario: Buses and Microbuses

The number of buses and microbuses and their activity levels were measured prior to the inauguration of the Metrobús corridor and were reported in the CDM document [6]. Fuel efficiency for diesel buses, gasoline microbuses, and microbuses that use liquid petroleum gas (LPG) were also reported in the CDM document. Fuel efficiency for heavy-duty vehicles that use compressed natural gas (CNG) reported by the Intergovernmental Panel on Climate Change (IPCC) was used for CNG microbuses [7]. The number of vehicles, their activity and fuel efficiency levels are shown in Table 4.1.

For microbuses and buses, average speeds were not measured for the CDM document. Emissions is estimated using an average speed of 17.4 km/hr (see Table 8.2), assuming that mean speed in a peak hour during school vacations reflects the overall mean speed on that corridor on an annual basis. Total kilometers traveled, fuel use, and speed are shown in Table 4.4.

Table 4.1. Number, activity level, speed and fuel efficiency of vehicles that were replaced with the Metrobús corridor. Activity levels were averaged over all 365 days per year [6, 7].

	Buses	Microbuses		
Fuel type	Diesel	Gasoline	Liquid Petroleum Gas (LPG)	Compressed Natural Gas (CNG)
Number of Vehicles	277	29	54	7
Activity (km/day)	140	130	130	130
Average Speed (km/hr)	17.4	17.4	17.4	17.4
Fuel Economy (km/l)	1.53	1.95	1.141	2.2*

*Units for CNG are km/m^3

The local government and the operators of the microbuses and buses agreed to remove from operation a fraction of buses and microbuses equivalent to the number previously operating along the route. No additional permits for circulating on competing routes were issued.

Baseline Scenario: Mode Change

A fraction of Metrobús users previously used private vehicles. For those users, we consider the reduction in emissions that occur from going from private to public transportation. To estimate the baseline emissions of those private vehicles we use mean private vehicle speed on Insurgentes during school vacation peak hours in 2004. Though using this speed may underestimate average speed, it is similar to overall average speed estimated in the CDM document (23.6 km/hr) [6]. Because the average speed on the corridor is expected to deteriorate in the baseline scenario, we believe use of measured peak speed during school vacations is appropriate. This method also does not account for the individuals who do not switch to private vehicles due to the presence of Metrobús, that would have switched had the lower quality bus and microbus service still been the only option.

In August of 2005, a survey of Metrobús users was conducted to evaluate the performance of the system. Over 1,622 users at all 34 stations and two terminals were surveyed; results have a margin of error of 2.9% [8]. Survey times were distributed over several weeks to sample peak travel times more heavily while considering all travel periods. Because the survey was completed soon after service began in June of 2005, the ridership may not have reached equilibrium.

The survey found that many of the Metrobús users previously did not travel on Insurgentes (27.3%). Many of those who did not travel on Insurgentes previously used the Metro (17.9%), particularly between the Indios Verdes Metro stop and the Glorieta Insurgentes, in the northern segment of the corridor. We assume that Metro did not decrease service due to the drop in demand, as the northern portion of the Indios Verdes to Ciudad Universitaria line continues to run at extremely high capacity. Therefore, we do not consider any changes in emissions related to Metro use. The remainder (9.4%) may have traveled by private vehicle, taxi, or microbus, or bus. Since the survey did not disaggregate those who previously did not travel on Insurgentes by mode, we do not explicitly consider changes in microbus or bus emissions on other routes. It is likely that changes in other routes would be very minor [6].

An interesting finding of the survey was that 4.6% of Metrobús users previously used a private car, and a further 1.8% previously used a taxi. We calculate the reduction in light-duty gasoline vehicle kilometers traveled using these data. In its most recent update, Metrobús reported that average weekday demand is 230,000 trips. Demand is 40% lower on Saturdays and 60% lower on Sundays [9]. Extrapolating to an annual basis, approximately 71.8 million trips are taken on the Metrobús per year. Metrobús employees have estimated that the average trip length is about 7 km [10]. Assuming that the taxi or private vehicle trip would have the same length, the total number of vehicle kilometers reduced is over 32 million per year.

We use the average observed speed of private vehicles on the corridor during school vacation peak hours prior to the Metrobús system's implementation (22 km/hr) to select emissions factors (see section 7 for details on the dataset). Fuel economy of private cars and taxis that previously circulated along the Insurgentes corridor (7.0 km/L) is taken from values measured for the CDM analysis [6]. Total kilometers traveled, fuel use, and speed are shown in Table 4.2 and 4.4.

Table 4.2. Data used to calculate the change in private vehicular traffic due to the Metrobús .

	Value	Source
Trips per week	1,380,000	[9]
Trips per year	71,760,000	--
Percent previously in taxi or private vehicle	6.4%	[8]
Average trip length (km)	7	[10]
Average speed (km/hr)	22	[11]
Fuel economy (km/L)	7.0	[6]

It is also possible that former bus and microbus users on Insurgentes may have changed to taxis or private cars due to the introduction of the Insurgentes system. However, given the very favorable approval ratings of the Metrobús, and the high number of users that switched from car and taxi to Metrobús, we estimate that this will be smaller than other emissions benefits that we do not consider, such as the increase in private vehicular traffic speeds along the Insurgentes corridor. Therefore, we do not quantify that possibility in this analysis.

Metrobús Scenario

Two companies manage the Metrobús vehicle fleet: the private company Corredor Insurgentes, SA de CV (CISA) and the governmental corporation Red de Transporte de Pasajeros del Distrito Federal (RTP). These entities operate under contract to Metrobús, a semi-independent department of the city government.

A total of 80 articulated buses were projected to operate in the corridor: 60 Volvos purchased by CISA, and a further 20 Scania vehicles purchased by RTP [6]. However, as of February, 2006, 89 buses were circulating in the corridor to accommodate the larger-than-expected demand [9]. RTP has converted 5 previously purchased buses to be used in the corridor, while CISA recently purchased an additional 4 vehicles.

Operations data on average kilometers traveled per day by Metrobús vehicles were not available. Based on projected demand, Metrobús anticipated that vehicles would travel an average of 243 km/day, after taking into account reserve vehicles, weekends and holidays [6]. We assume that the number of kilometers traveled by day would not have changed substantially from the values projected, despite the increase in demand.

Fuel economy of buses is very sensitive to the conditions under which the vehicle is driven [12]. Under controlled laboratory conditions, Scania articulated buses have a fuel economy of 1.52 km/l [6]. In León, Guanajuato, a bus rapid transit system experienced fuel economies of between 1.0 and 1.2 km/l [13]. Because driving conditions are so important for average fuel economy, we base our estimate of fuel economy on the real values observed in the León BRT. We estimate fuel economy to be 1.1 km/l. Metrobús drivers are currently completing a course to improve their fuel economy, so this estimate may underestimate future fuel economy along Insurgentes [10].

The Metrobús was projected to run at a velocity of 23 km/hr [14]. However, in practice, the velocity of the Metrobús has been somewhat lower. On average (considering both peak hours and other time periods) Metrobús travels at approximately 21 km/hr [9]. Rather than use the emissions factors previously calculated for the projected speed (presented in Appendix 1), we use emissions factors developed for travel at 21 km/hr (see section 5). Emission factors were calculated assuming that all buses were purchased in 2005 or 2006, and none were replaced (see section 5 for more details). Total kilometers traveled, fuel used, and speeds are shown in Table 4.4.

To check the validity of the operations data for the new Metrobús system, it can be compared to data from the Optibus bus rapid transit system in León, Mexico. Because Optibus has been operating since 2003, additional operations data are available. The Optibus system is composed of three lines, totaling 26 kilometers with 53 stations [15]. Bus activity levels for both Metrobús and Optibus are also shown in Table 4.3 for comparison purposes.

Table 4.3. Activity values for the Metrobús and Optibus systems.

Value	Metrobús	Reference	Optibus	Reference
Number of buses	89	[9]	52	[15]
Activity (km/day)	243*	[6]	160	[13]
Average Velocity (km/hr)	21	[9]	15-21	[15]
Fuel Economy (km/L)	1.52*	[6]	1.0-1.2	[13]

*Projected values (see text)

Table 4.4. Annual difference in vehicle kilometers traveled and fuel use, 2005 to 2015, Metrobús scenario less baseline scenario. *Units for CNG are m^3.

Vehicle Type	Change in VKT (km)	Change in Fuel Use (L)	Average Speed (km/hr)
Metrobús	6,800,000	6,200,000	21
Diesel Bus	-14,000,000	-9,300,000	17.4
Microbus (Gasoline)	-1,400,000	-710,000	17.4
Microbus (LPG)	-2,600,000	-2,200,000	17.4
Microbus (CNG)	-330,000	-150,000*	17.4
Private Vehicle	-23,000,000	-3,300,000	22

*Units for CNG are m^3

V. Change in Emissions

Emissions factors were developed for this project and are detailed in Appendix 2 ("Report on emissions factors and fuel economy"). A summary of the methods used and updates to the original report follow.

Local Emissions

The model MOBILE6-Mexico was used to calculate emission factors for fine particulate matter ($PM_{2.5}$), nitrogen oxides (NO_x) and total hydrocarbons (THC). Fleet average emission factors were obtained for each vehicle type and year. Emission factors were calculated considering projected changes in fuel quality and vehicle emissions standards, namely a reduction in fuel sulfur levels combined with introduction of Tier 2 vehicular technologies. The assumptions used to develop the scenario were consistent with the regulations in development at the time of the analysis (for details, see Table 5.1).

Table 5.1. Changes in fuel quality and vehicle technology incorporated into projected emissions factors [16].

Change in technology or fuel quality	Implementation Schedule
Tier 2 technology in new light-duty gasoline vehicles (LDGV) and light-duty gasoline trucks (LDGT1 and LDGT2)	2006 (25%) 2007 (50%) 2008 (75%) 2009 (100%)
Tier 2 technology in new light-duty gasoline trucks (LDGT3 and LDGT4)	2010 (50%) 2011 (100%)
EPA 2007 technology in new heavy-duty diesel vehicles	2009 (100%)
EPA 2004 diesel articulated buses*	2005 to 2008
EPA 2007 diesel articulated buses*	2009 to 2012
Gasoline with 30 ppm mean sulfur, and 80 ppm maximum sulfur	2006 to 2020
Maximum 300 ppm sulfur diesel	2005 to 2008
Maximum 15 ppm sulfur diesel	2009 to 2020

*Diesel articulated buses circulate exclusively in the proposed bus rapid transit corridors.

In order to obtain fleet average emission factors, the Mexico City vehicle fleet's age distribution and average annual mileage were projected. The fleet's age distribution was projected using the methodology of Mexico City's 1998 emissions inventory, which projected the fleet's age distribution through 2010 [17]. Data from the mandatory vehicle emissions testing program were used to estimate average annual mileage.

The Mobile model does not evaluate local emission factors for vehicles that use compressed natural gas or liquid petroleum gas. Therefore, emissions factors published by the IPCC were used for microbuses that use CNG or LPG fuels [7].

Some of the vehicle types discussed in section 4 correspond to more than one Mobile or IPCC vehicle category. For those vehicle types, data on the vehicle fleet were used to determine the correspondence of the different classification categories. In order to determine the appropriate Mobile vehicle categories, vehicle fleet data from the Melgar database were used. Classifications are reported in Table 5.2 [18]. For estimates of emissions control technology in the vehicle fleet, the projected vehicle fleet age distribution reported in Appendix 2 was used (Table 5.6 on page 17). Final local emissions factors for buses, microbuses, taxis, and private cars are shown in Tables 5.4, 5.5 and 5.6.

Table 5.2. Correspondence of vehicles groups to Mobile vehicle categories.

Vehicle Type	Mobile Category	Percent of Total
Private Car	LDGV	89.85%
	LDGT12	8.48%
	LDGT34	1.66%
Taxi	LDGV	100%
Microbus (Gasoline)	HDGV3	100%
Bus	HDDB	100%
Metrobús	HDDV8b	100%

Emissions factors for articulated buses presented in Appendix 2 were calculated assuming an average speed of 27 km/hr and based on the assumption that new vehicles will be added as the Metrobús system expands to 33 corridors. However, the observed average speed of the Metrobús-Insurgentes was only 21 km/hr. Emission factors for articulated buses were recalculated for this report, assuming that 85 buses are purchased in 2005, that 4 additional buses are purchased in 2006, and that buses travel an average of 21 km/hr. Emission factors are shown in Tables 5.3, 5.4 and 5.5.

Table 5.3. Final emissions factors for total hydrocarbons (THC). Units are g/km.

Year	**Private Vehicle**	**Taxi**	**LPG Microbus**	**CNG Microbus**	**Gasoline Microbus**	**Diesel Bus**	**Metrobús**
2005	2.08	1.88	5.30	8.04	11.71	9.67	0.75
2006	1.81	1.64	5.30	8.04	11.71	7.76	0.75
2007	1.55	1.38	5.30	8.04	11.71	6.73	0.75
2008	1.35	1.23	5.30	8.04	11.71	5.86	0.75
2009	1.15	1.05	5.30	8.04	11.71	5.40	0.75
2010	1.00	0.91	5.30	8.04	11.71	5.26	0.75
2011	0.92	0.83	5.30	8.04	11.71	5.10	0.75
2012	0.79	0.72	5.30	8.04	11.71	4.85	0.75
2013	0.72	0.66	5.30	8.04	11.71	4.43	0.75
2014	0.66	0.60	5.30	8.04	11.71	4.11	0.75
2015	0.61	0.55	5.30	8.04	11.71	3.85	0.75

Table 5.4. Final emissions factors for nitrogen oxides (NO_x). Units are g/km.

Year	Private Vehicle	Taxi	LPG Microbus	CNG Microbus	Gasoline Microbus	Diesel Bus	Metrobús
2005	0.83	0.80	4.43	4.43	3.41	58.57	4.55
2006	0.75	0.72	4.43	4.43	3.41	57.49	4.56
2007	0.73	0.69	4.43	4.43	3.41	57.54	4.57
2008	0.70	0.66	4.43	4.43	3.41	54.76	4.58
2009	0.69	0.65	4.43	4.43	3.41	52.32	4.59
2010	0.65	0.60	4.43	4.43	3.41	49.73	4.60
2011	0.62	0.56	4.43	4.43	3.41	46.02	4.60
2012	0.57	0.51	4.43	4.43	3.41	42.65	4.60
2013	0.56	0.50	4.43	4.43	3.41	40.88	4.60
2014	0.52	0.46	4.43	4.43	3.41	37.50	4.60
2015	0.48	0.42	4.43	4.43	3.41	33.39	4.60

Table 5.5. Final emissions factors for fine particulate matter ($PM_{2.5}$). Note that $PM_{2.5}$ emissions were not calculated for microbuses using LPG or CNG fuels. Units are g/km.

Year	Private Vehicle	Taxi	Gasoline Microbus	Diesel Bus	Metrobús
2005	0.011	0.011	0.056	0.421	0.153
2006	0.007	0.007	0.056	0.364	0.153
2007	0.007	0.007	0.056	0.341	0.153
2008	0.007	0.007	0.056	0.321	0.153
2009	0.007	0.007	0.056	0.268	0.140
2010	0.007	0.007	0.056	0.231	0.140
2011	0.007	0.007	0.056	0.200	0.140
2012	0.007	0.007	0.056	0.173	0.140
2013	0.007	0.007	0.056	0.156	0.140
2014	0.007	0.007	0.056	0.126	0.140
2015	0.007	0.007	0.056	0.107	0.140

Table 5.6. Proportion of vehicles in each age class, by year, used to apply official IPCC emission factors. IPCC emission factors are used for all greenhouse gas emissions, and for local emissions from GNC and LPG microbuses.

Vehicle Type	Model Year	Calendar Year										
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Passenger Cars	≤ 1992	24%	20%	16%	14%	11%	10%	8%	7%	5%	5%	4%
	1993-1998	15%	13%	12%	10%	9%	8%	7%	6%	5%	4%	4%
	≥ 1999	61%	67%	72%	76%	80%	83%	85%	87%	89%	91%	92%
Taxis	≤ 1992	5%	4%	3%	3%	2%	2%	2%	1%	1%	1%	0%
	1993-1998	63%	60%	48%	33%	19%	11%	4%	3%	3%	2%	2%
	≥ 1999	32%	37%	49%	64%	79%	87%	95%	96%	96%	97%	97%
Microbuses	≤ 1992	13%	13%	13%	13%	13%	13%	13%	13%	13%	13%	13%
	1993-1998	82%	82%	82%	82%	82%	82%	82%	82%	82%	82%	82%
	≥ 1999	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%
Microbuses	≤ 1994	59%	59%	59%	59%	59%	59%	59%	59%	59%	59%	59%
	≥ 1995	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%
Buses	≤ 1993	24%	20%	17%	16%	15%	13%	11%	10%	9%	8%	6%
	≥ 1994	76%	80%	83%	84%	85%	87%	89%	90%	91%	92%	94%

Emissions of sulfur dioxide are calculated using mass-balance. Mean sulfur content for gasoline and diesel are taken from Table 5.1, and for LPG and CNG from the Mexico City emissions inventory for 2002 [19]. A small percentage of sulfur is emitted as particulate matter and is incorporated into emission factors for $PM_{2.5}$. Because that portion of fuel sulfur is not emitted as sulfur dioxide, it must be accounted for in the mass balance equation. We use inventory calculations for gas and diesel to estimate the percent of sulfur emitted as particulate matter [19]. As we do not develop particulate matter emission factors for LPG or CNG, we assume all sulfur is emitted as sulfur dioxide. Grams of sulfur dioxide emitted per kg fuel are given in Table 5.7. In order to calculate factors with volume of fuel in the denominator, the fuel densities found in Table 5.8 were used [20].

Table 5.7. Sulfur dioxide emissions factors [19].

Fuel	Years	Mean Fuel Sulfur Content	Percent emitted as SO_2	Emission Factor (g/kg)
Gasoline	2005	300 ppm	96%	0.576
Gasoline	2006-2015	30 ppm	96%	0.0576
Diesel	2005-2008	300 ppm	97%	0.582
Diesel	2009-2015	15 ppm	97%	0.029
LPG	2005-2015	140 ppm	100%	0.280
CNG	2005-2015	1.2 ppm	100%	0.0024

Table 5.8. Density of fuels sold in the MCMA as reported in the 2002 emissions inventory [20]. Standard density of CNG reported by the IPCC was used [7].

Fuel	Density
Gasoline	0.730 kg/L
Diesel	0.835 kg/L
Liquid Petroleum Gas (LPG)	0.540 kg/L
Compressed Natural Gas (CNG)	0.72 kg/m^3

Global Emissions Factors

Official IPCC emissions factors were used to quantify greenhouse gas pollutants for all vehicles (shown in Appendix 2). Conversion factors in Table 5.6 were used to calculate emission factors for the vehicle types used in this analysis. Final emission factors are shown in Table 5.9. IPCC emission factors for gasoline, diesel and LPG vehicles are given in units g/kg. Fuel densities in Table 5.8 were used to calculate total emissions.

Table 5.9. Average emissions factors for methane (CH_3), nitrous oxide (N_2O), and carbon dioxide (CO_2). Units are g/kg.

Vehicle Type	Methane	Nitrous Oxide	Carbon Dioxide
Private Vehicle	0.40	1.68	3172
Taxi	0.37	1.83	3172
Microbus (LPG)	0.95	--	3000
Microbus (CNG)	24.14	--	2750
Microbus (Gasoline)	0.28	1.67	3172
Diesel Bus	0.15	0.08	3172
Metrobús	0.14	0.08	3172

Calculating change in emissions

Using the emissions factors calculated in Tables 5.4 to 5.6, the total difference in emissions can be calculated using the following equation:

$$E_k = \sum_i \Delta KRV_i \times FE_{ik} \times N_i \qquad \textit{Equation 5.1}$$

where:
E_k = Total vehicle emissions of contaminant k [g/year]
ΔKRV_i = Change in average vehicle kilometers traveled for vehicle type i [km/year]
FE_{ik} = Emission factor for vehicle type i, of contaminant k [g/km]
N_i = Number of vehicles (or number of trips) of type i

In the case of greenhouse gases and sulfur dioxide emissions, the following equation was used:

$$E_k = \sum_i \Delta KRV_i \times D_j \times FE_{jk} \times N_i \div R_{ij} \qquad \textit{Equation 5.2}$$

where:
E_k = Total vehicle emissions of contaminant k [g/year]
ΔKRV_i = Average vehicle kilometers traveled for vehicle type i [km/year]
D_j = Density of fuel type j [kg/L]
FE_{ik} = Emission factor for fuel type j, of contaminant k [g/kg]
N_i = Number of vehicles (or number of trips) of type i
R_{ij} = Fuel economy of vehicle type i, using fuel type j [km/L]

Average annual change in emissions, by vehicle type, is shown in Figures 5.1 and 5.2. The total change in emissions, summed over the vehicle types, is listed in Table 5.10.

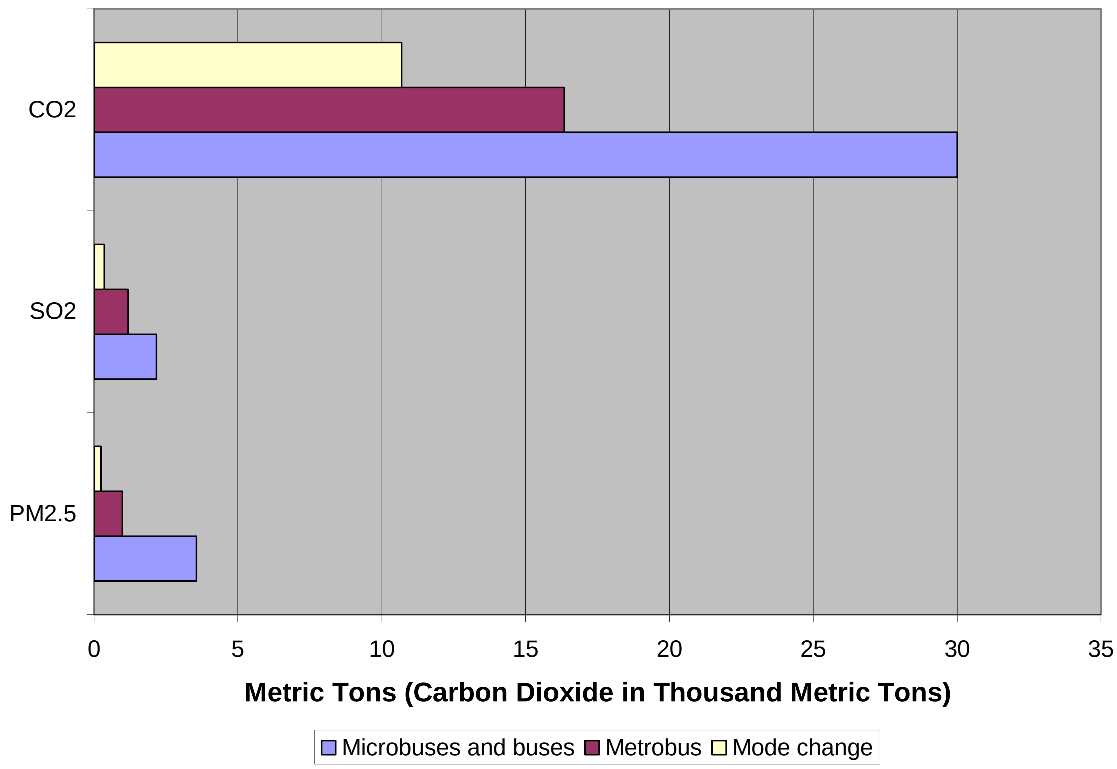

Figure 5.1. Average annual change in emissions by source, of carbon dioxide (CO_2), sulfur dioxide (SO_2) and fine particulate matter ($PM_{2.5}$). Note that the units are thousand tons for CO_2, and tons for SO_2 and $PM_{2.5}$. Mode change refers to the change in emissions that occurs because users of private vehicles and taxis switched to Metrobús.

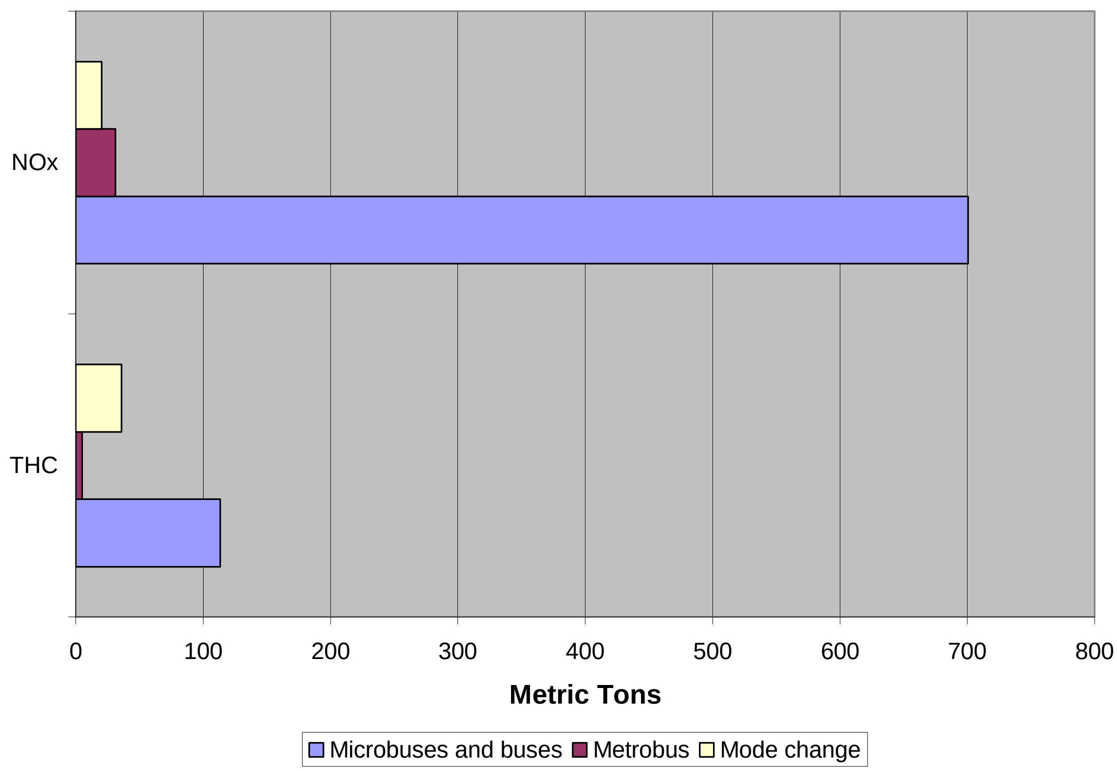

Figure 5.2. Average annual change in emissions by source, nitrogen oxides (NO_x) and total hydrocarbons (THC). Mode change refers to the change in emissions that occurs because users of private vehicles and taxis switched to Metrobús.

Table 5.10. Difference in emissions between the baseline and the Metrobús scenario in the Insurgentes corridor (metric tons)*.

Year	**THC**	**NO_x**	**$PM_{2.5}$**	**SO_2**	**CO_2**	**CH_3**	**N_2O**
2005	-115	-421	-2.7	-2.0	-12,182	-2.6	-3.1
2006	-194	-824	-4.4	-2.1	-24,364	-5.2	-6.5
2007	-171	-824	-4.1	-2.1	-24,364	-5.2	-6.6
2008	-153	-784	-3.8	-2.1	-24,364	-5.1	-6.8
2009	-140	-749	-3.1	-0.6	-24,364	-5.0	-6.9
2010	-133	-711	-2.6	-0.6	-24,364	-5.0	-7.0
2011	-128	-657	-2.2	-0.6	-24,364	-5.0	-7.1
2012	-121	-608	-1.8	-0.6	-24,364	-4.9	-7.1
2013	-113	-582	-1.6	-0.6	-24,364	-4.9	-7.2
2014	-106	-533	-1.1	-0.6	-24,364	-4.9	-7.2
2015	-101	-474	-0.9	-0.6	-24,364	-4.9	-7.3

*Values are negative because emissions were lower in the Metrobús scenario.

VI. Health Benefits

The benefits of controlling vehicular pollution may be realized in several ways, including reductions in population mortality and morbidity; improvements in visibility; reduced damages to crops, vegetation, ecosystems, buildings, and materials; and reduction in pollutants contributing to climate change. Comprehensive benefit-cost analyses typically address each of these effects [21-24]. The results of many of these studies indicate that population health improvements often comprise the most substantial fraction of monetized benefits. Of these health improvements, the majority of monetized benefits are usually associated with reductions in airborne fine particulate matter ($PM_{2.5}$) [25]. Therefore, quantitative estimates of benefits in this analysis focus on the health benefits of reducing ambient $PM_{2.5}$ concentrations.

Health benefits are a function of the emissions reduction, the proportion of these emissions that would have been inhaled as $PM_{2.5}$, the concentration-response coefficient, and the monetary value of a unit health risk (Figure 3.1). The emissions reduction was calculated in section 5, while this section summarizes the values used in the next three steps. We assume that the changes in emissions of four pollutants, primary $PM_{2.5}$, oxides of nitrogen (NO_x), sulfur dioxide (SO_2), and hydrocarbons (HC) resulted in changes in airborne $PM_{2.5}$ concentration. The change in annual average concentration of airborne primary PM and secondary PM (formed in the atmosphere from sulfur dioxide, nitrogen oxides, and hydrocarbon gases) resulting from these emissions was then assumed to be associated with changes in population mortality and morbidity. Finally, a monetary value was attached to each health impact to calculate total benefits. More details on the methods used can be found in Appendix 3.

Modeling the change in concentration of atmospheric pollutants

Reduced-form air quality models were used to calculate changes in fine particulate matter ($PM_{2.5}$) concentrations from projected changes in total vehicular emissions. Atmospheric concentration of primary particles (emitted in vehicle exhaust) and secondary particles (those that form in the atmosphere from vehicle emissions, such as NO_x, SO_2, and THC) were considered. Ambient concentrations were estimated using three models: 1) regression model; 2) box model; and 3) particle composition model. Details of the models are as follows:

1. The *regression model* is based on U.S. air quality models. This model predicts population-weighted concentrations from data on emissions and population density [26]. In the case of the MCMA, this model likely underestimates exposure because it does not take into account local meteorological and geographic conditions, which facilitate the formation of and prevent the dispersion of airborne contaminants in the Basin of Mexico.

2. The *box model* considers the dispersion of primary particles in the MCMA, treating the basin in which the city is located as a well-mixed box. This model only predicts exposure to primary particles.

3. The *particle composition model* uses data on particle composition in the MCMA [27]. This data is combined with the MCMA's emissions inventory to calculate the relative contribution of primary emissions (gases and particles) to the final concentration of particles in the atmosphere. This model has limitations because

it only considers emissions reported in the MCMA's emissions inventory, ignoring sources from outside of the basin.

Given the limitations of each model, the concentration of $PM_{2.5}$ in the MCMA was calculated using the average result of the three models.

Evaluation of avoided morbidity and mortality

Concentration-response functions were used with the results of the air quality models to estimate the potential health benefits of the estimated reduction in vehicular emissions. The concentration-response functions were obtained from epidemiological studies that relate ambient concentrations of $PM_{2.5}$ to a health response, such as morbidity or mortality. Using the best available national and international epidemiological studies, the following health impacts were evaluated :

- Cardiopulmonary mortality
- Lung cancer mortality
- Infant mortality, caused by an acute respiratory infection
- Sudden infant death syndrome
- Chronic bronchitis
- Minor restricted activity days
- Work loss days

The following equation was used to calculate health impacts:

$$I = T * P * F * \frac{e^{\Delta C \hat{\beta}} - 1}{e^{\Delta C \hat{\beta}}} \qquad \textit{Equation 6.1}$$

where:

I = health impact (e.g. avoided deaths or illnesses)
T = mortality and morbidity incidence in the population
P = total population
F = fraction of the population affected (depending on the health impact)
$\hat{\beta}$ = concentration-response coefficient
ΔC = change in population-weighted concentration

In order to use Equation 6.1, data on the age structure of the Mexican population in future years is needed. CONAPO, the National Population Council, has projected the Mexican population to 2050 [28, 29]. CONAPO data were used when projecting health impacts. Table 6.1 lists the data used in the health impact calculation.

Table 6.1. Inputs for the health impact calculation[1]

Impact	Age group affected	Percent of the total population in the age group, 2000 (%)	Percent of the total population in the age group, 2030 (%)	Concentration-Response Coefficient ($\hat{\beta}$)*	Incidence Rate (per 1000)
Cardiopulmonary mortality	>30 years	38	53	0.00892	3.42
Lung cancer mortality	>30 years	38	53	0.013	0.17
Infant mortality, acute respiratory infections	Between 4 weeks and 1 year	2	1.5	0.018**	2.31
Sudden infant death syndrome	Between 4 weeks and 1 year	2	1.5	0.011**	0.12
Chronic bronchitis	>30 years	38	53	0.017	14
Minor restricted activity days	>15 years	67	77	0.0074	7800+
Work loss days	Workers	42	49	0.0046	2170+

*Coefficient for a 1 µg/m^3 change in $PM_{2.5}$.
** Coefficient for a 1 µg/m^3 change in PM_{10}.
+ Incidence rates are greater than 1000 because on average, individuals experience more than one episode per year.

Calculating the economic value of health benefits

In order to compare health benefits to the investment associated with low sulfur fuels, health benefits must be converted to monetary terms. In this study, equation 6.2 was used to calculate the economic value of the benefits:

$$IM_{T(\$)} = \sum^{i} (V_{i(\$/caso)} \times I_{i\,(casos)}) \qquad \textit{Equation 6.2}$$

where:
IM_T = total monetary value (dollars per year)
V_i = unit value of health effect *i* (for example, the value to society of avoiding a case of chronic bronchitis)
I_i = number of cases of health effect *i* avoided (for example, deaths)

Two methods are typically used to obtain the unit value of a health impact (V_i): the *willingness to pay (WTP)* and *cost of illness*. *Willingness to pay* determines the

[1] See Appendix 3 for sources of C-R functions.

amount that one is willing to pay to reduce the risk of sickness or death (thereby taking into account pain and suffering), while *costs of illness* only includes the costs of treatment, such as doctors' visits or medicines. Contingent valuation or hedonic wages studies can be used to determine WTP. Contingent valuation is a method where surveys are used to simulate a hypothetical market, where the interviewer offers the interviewee the chance to purchase a reduction in health risk. On the other hand, a hedonic wage study determines the relationship between job safety and wages.

Results of contingent valuation and hedonic wage studies describe the monetary value assigned to a unit risk. Dividing willingness to pay for a unit risk by the risk level provides the value of a statistical life (VSL) or the value of a statistical case of morbidity.

In this case, results of U.S. studies were adjusted for Mexican income levels [30]. To adjust the U.S. values for Mexican income, the following equation was used:

$$V_{México} = V_{US} \times \left(\frac{I_{México}}{I_{us}} \right)^{\varepsilon} \qquad \textit{Equation 6.3}$$

where:
V = value of a statistical life or case for a population
I = income for the population
ε = income elasticity of health

For the purposes of valuing health effects, the income elasticity of WTP is the percentage change in willingness to pay that corresponds to a percentage change in income. In this case, given that the exact value of income elasticity of health is unknown, a range of 0.5 to 2 was used to calculate a range of WTP for Mexican income levels [25]. An intermediate value, calculated with an elasticity of 1, is presented in Table 6.2.

In order to calculate the economic impact of work loss days, only the cost of sickness was considered, that is, the income loss for failing to work, quantified using the average salary. Monetary values are shown in Table 6.2.

Table 6.2. Monetary values per unit health impact

Health impact	**Monetary values in USD, adjusted for inflation to 2005**
Cardiopulmonary mortality	750,000
Lung cancer mortality	750,000
Infant mortality from acute respiratory infections	750,000
Sudden infant death syndrome	750,000
Chronic bronchitis	41,000
Minor restricted activity days	14
Work loss days	15*

*Productivity loss

Results

The Metrobús system's substantial emissions benefits are expected to eliminate an average of 6100 work loss days, 660 restricted activity days, 12 new cases of chronic bronchitis, and 3 deaths per year. These health benefits are estimated to provide the citizens of Mexico City an average of $3 million (USD) in health benefits each year. Annual health benefits decrease during the period modeled because the difference in vehicle activity and emissions from Metrobús is considered constant, while vehicle emissions from private vehicles and diesel buses that would otherwise circulate on Insurgentes are expected to decrease as vehicle technologies improve.

Table 6.3. The health benefits of the emissions eliminated by replacing buses and microbuses with articulated buses on Insurgentes Avenue. Benefits are in U.S. dollars, adjusted for inflation to 2005.

Year	Deaths	Cases of Chronic Bronchitis	Minor Restricted Activity Days	Work Loss Days	Economic Value (USD)
2005	2	8	470	4400	2,000,000
2006	3	16	870	8100	3,700,000
2007	3	15	860	8000	3,600,000
2008	3	15	830	7700	3,500,000
2009	3	14	760	7000	3,300,000
2010	3	13	710	6600	3,100,000
2011	3	12	650	6000	2,900,000
2012	2	11	600	5500	2,700,000
2013	2	11	570	5200	2,600,000
2014	2	10	510	4700	2,400,000
2015	2	9	450	4100	2,100,000

VII. Greenhouse gas benefits

A principal goal of the Integrated Environmental Strategies (IES) program is to evaluate the potential for co-benefits, that is, policies that reduce both local pollutants and greenhouse gas emissions. The Metrobús corridor on Insurgentes Avenue is expected to reduce greenhouse gases as well as local emissions; in this section, we evaluate the magnitude of greenhouse gas benefits.

In section 5, the total reduction in emissions of three greenhouse gases, carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) were evaluated. Some greenhouse gases have higher radiative efficiency, that is, they will contribute to climate change to a greater extent. In order to evaluate the total greenhouse gas emissions reduction, taking into account the efficiency of the three emission pollutants evaluated, the total CO_2-equivalent tons of reduction was calculated. The global warming potentials of nitrous oxide and methane, in terms of tons of carbon dioxide, have been published by the Intergovernmental Panel on Climate Change [31]. Because some gases have longer half-lives than others, the time horizon over which the gas is evaluated affects the calculated global warming potential. Values are shown in Table 7.1.

Table 7.1. Global warming potential of three greenhouse gases evaluated in this analysis, by time horizon [31].

Greenhouse Gas	**Time Horizon**		
	20 years	100 years	500 years
Carbon Dioxide (CO_2)	1	1	1
Methane (CH_4)	62	23	7
Nitrous Oxide (N_2O)	275	296	156

In order to assess the importance of the time horizon selected, we calculated the total greenhouse-gas emissions in CO_2-ton equivalents using each of the three time horizons presented by the IPCC. The results are presented in Table 7.2. As can be seen, the results are relatively insensitive to the time horizon selected. This is because the majority of emissions reduced are CO_2 emissions. Therefore, we use the central time horizon, 100 years.

Table 7.2. Total CO_2-ton equivalents eliminated by the Metrobús-Insurgentes corridor, by year, in thousand tons.

Year	**Time Horizon**		
	20 years	100 years	500 years
2005	13.3	13.2	12.7
2006	26.6	26.5	25.5
2007	26.6	26.5	25.5
2008	26.6	26.6	25.5
2009	26.7	26.6	25.5
2010	26.7	26.6	25.6
2011	26.7	26.7	25.6
2012	26.7	26.7	25.6
2013	26.7	26.7	25.6
2014	26.8	26.7	25.6
2015	26.8	26.7	25.6
Total	280.2	279.4	268.3

The social benefits of reducing greenhouse gas emissions are extremely difficult to estimate [32]. Some of the difficulties include:

- Scientific uncertainty about climate change impacts.
- Aggregating economic benefits across societies with different levels of economic resources. Usual measures of social benefits, such as willingness to pay, depend on the economic resources and output of the society in question. However, valuing losses (such as loss to life) in developed countries higher than losses in developing countries raises serious ethical questions.

- Selecting an appropriate discount rate. Because the social impacts of climate change will occur over a long time-scale, the current value of greenhouse gas emissions is extremely sensitive to the discount rate used.

The IPCC has put forth an initial estimate that a doubling of carbon dioxide would have impacts on the order of 1.5% to 2% of current world GDP [32]. Because these estimates do not evaluate the social cost of marginal changes in CO_2 emissions, the marginal social benefit of reducing one ton of CO_2 emissions cannot be calculated.

In this report, we do not attach a monetary value to CO_2 emissions reductions. Instead, we value total health benefits accrued from reductions in local emissions, and present the total greenhouse gas reductions in tons of CO_2-equivalents as an additional benefit. The Metrobús system operating on Insurgentes Avenue is expected to eliminate 280 thousand CO_2-equivalent tons from 2005 to 2015.

VIII. Travel Time Benefits

In addition to important impacts on population health and global sustainability, the Metrobús will also provide economic benefits in the form of time saved by users of the public transportation system. The change in travel time during peak hours was estimated using the results of a study of personal exposure to air pollutants for commuters on the Insurgentes corridor, before and after the construction of the Metrobús corridor [11, 33]. Researchers at the Instituto Nacional de Ecología (INE) and the Centro de Transporte Sustentable (CTS) measured personal exposure to benzene, fine particulate matter ($PM_{2.5}$), and respirable particulate matter (PM_{10}). The first campaign took place during June to August of 2004, prior to the construction of the Metrobús corridor. The second took place between August and October of 2005, several months after Metrobús service began in June of 2005.

In each campaign, technicians boarded a bus or microbus (in 2004), the Metrobús (in 2005), or a private vehicle at Indios Verdes, located at the northern end of the Metrobús route, between 7 and 9 a.m. The average time of departure was 7:38 a.m. The technician recorded the time of boarding the vehicle and began monitoring pollutants. Upon reaching the San Angel microbus station (in 2004) or the Dr. Galvez station (in 2005), slightly less than 20 kilometers to the south, the technician again recorded the time. While the primary purpose of this study was to measure the difference in exposure after the system was introduced, it also provides data on the change in travel times after the Metrobús system was introduced. Table 8.1 shows the number of trips for which travel time was measured, by year and vehicle type.

Table 8.1. Number of trips in each campaign, by vehicle type, for which the total travel time was recorded.

Campaign	**Summer 2004**		**Summer 2005**	
	Number of trips	Average time of departure	Number of trips	Average time of departure
Private Vehicle	33	7:35 am	10	7:24 am
Microbus	66	7:46 am	--	
Bus	66	7:33 am	--	

Metrobús	--		68	7:40 am

In this analysis, we compare the total trip time in public transportation in the summer of 2004 to the total trip time in public transportation in the summer/fall of 2005 to determine the time savings provided to users of the Metrobús users that previously used buses and microbuses. In order to be consistent with the analysis of emissions, which only considers the emissions change caused by the change in public transportation technology, we do not consider the possible change in travel time that users of private vehicles experience.

Previous analysis of the 2004 data have indicated that the time at which the trip began and whether the trip occurred during school vacation affect the total trip time [33]. Wöhrnschimmel *et al.* observed that the average trip time, and the variation in total time, was lower in the weeks during school summer vacation. In addition, the authors noted that there was a statistically significant relationship between departure time and total travel time: for departures between 7:30 am and 7:56 am, a departure delay of 15 minutes increased total trip time approximately 11 minutes. Finally, the authors noted that there was no significant difference in travel time between the microbus and the bus.

We compare the total travel time for users of public transportation traveling the full Indios Verdes to San Angel route in 2004 to the total travel time in 2005. Based on the observations of Wöhrnschimmel *et al.*, we combine the travel time observations for bus and microbus in 2004. Travel time was significantly lower during the school vacation period as compared to school year travel times in 2004, while school vacations did not have a significant impact on travel time in the Metrobús. Therefore, we calculate mean travel times separately for vacation period and school year period. Mean travel times, speeds, and time saved are shown in Table 8.2.

Table 8.2. Mean travel time, mean speed, and mean time saved for users of public transportation traveling from Indios Verdes to San Angel during peak hours. Velocity was calculated using a distance of 19.5 km [14].

Period	School Vacations		School year	
Year	2004	2005	2004	2005
Time (minutes)	67:06	58:30	81:13	58:25
Velocity (km/hr)	17.4	20.0	14.4	20.0
Change in travel time (min/km)	0:26		1:10	

Because the variance of travel times was much higher in 2004 than 2005, we ran two nonparametric ANOVA tests: one comparing travel time during school vacation, and one comparing travel time while school was in session. The difference in travel time was found to be statistically significant (Mann-Whitney $p<0.0001$ for the school year and school vacations comparisons). Finally, given the importance of start time observed by Wöhrnschimmel *et al.*, we investigated the impact of including start time in our statistical model. We found that results were not sensitive to the inclusion of starting time.

In order to determine the total number of person-hours saved, we first calculate average weekday demand during peak hours. Though some time savings may occur during non-peak hours, such savings are likely smaller in magnitude and we do not have measured velocities for non-peak hours. Metrobús has reported an average demand of 230,000 trips per weekday. We estimate that 50% of total trips occur during a peak hour [5]. Therefore, on an average weekday, 115,000 trips occur on Metrobús during peak hours. It is important to only consider those users who formerly used road-based public transportation, since we do not have data on the time spent in other transportation modes. According to survey data, 76% of Metrobús users formerly used microbuses or buses. We assume that the average trip length is 7 km to calculate total time savings [10].

From the Education Department's official calendar, we calculate 170 school days, and an additional 70 work days during the school vacation period [34]. Mean hourly wage of Metrobús users can be used as a proxy for the social value of time lost. However, in some cases (such as leisure trips) median wage may overestimate the social value of time. In addition, due to large informal labor sector in Mexico City, calculating mean hourly wage is difficult. We use a social value of time for users of public transportation in Mexico that was previously estimated by ETEISA: 6.26 pesos per hour, or 57.5 U.S. cents [2].

Table 8.3. Data used to calculate total time saved per year by Metrobús users.

	Value	**Reference**
Trips per weekday	230,000	[9]
Trips during a peak hour	115,000	[5]
Former users of public transportation (fraction)	0.76	[8]
Former users of public transportation	87,113	--
Total peak hour trips during school term	14,800,000	--
Total peak hour trips during school vacation	6,100,000	--
Average trip length (km)	7	[10]
Total time saved per year (hours)	2,330,000	--
Unit monetary value (U.S. cents/hour)	57.5	[2]
Annual value of total time saved (U.S. dollars)	1,340,000	--

In addition to the change in average travel time, the change in variability in travel time is a very important benefit to users of public transportation. As discussed above, the sample of travel times in the summer of 2005 showed very little variation: the standard deviation of travel time was only 2.5 minutes. Assuming travel time is normally distributed, that means that about 60% of trips from Indios Verdes have a duration that differs 2.5 minutes or less from the mean. The observed distribution of travel times indicates that a person who travels the entire Metrobús route during peak hours is five minutes late less than 5% of the time—and being extremely late is quite rare.

In contrast, prior to the implementation of the Metrobús system, the travel time of the entire route from Indios Verdes to Dr. Galvez in a bus or microbus had a standard deviation of 14.6 minutes. The data show that the same person had a 25% chance of being 7 minutes late, and a 5% chance of being 30 minutes late, if that person calculated his or her travel time using the mean travel time on the route.

Data on individual travel preferences show that people are risk averse with respect to travel time. This means that, on average, a transportation user strongly dislikes uncertainty about travel time—such that most people will prefer a slow, but certain, travel option over another that is on average faster, but shows high uncertainty. Therefore, the reduction in uncertainty about travel time as a result of the Metrobús system may provide even higher benefits to its users than the reduction in average travel time. We do not quantify this benefit, as we would need to survey users to determine their willingness to pay for a more reliable transportation service. However, it should be considered as another, potentially large, source of benefits provided by the Metrobús system.

IX. Costs

The cost of a bus rapid transit system can be divided into capital costs and operating costs. In systems around the world, infrastructure costs have varied from under \$1 million per kilometer to over \$10 million per kilometer [1]. Operating costs are dependent on local prevailing wages. In order to estimate costs of the Metrobús system that operates on Insurgentes, reported expenditures were used to calculate costs.

Capital costs include the infrastructure investments of construction of stations, lane separations, and miscellaneous installation of signs, traffic signals, and other aesthetic installations. In addition, a fare collection system must be installed and new articulated buses purchased.

To calculate the change in operating costs, the cost of operating the old microbuses and buses that were eliminated must first be calculated. A complete analysis would consider change in wages, change in vehicle maintenance costs, and change in fuel use. In this analysis, we do not consider changes in operation wages. City planners decided to hire all displaced microbus and bus drivers as Metrobús employees. We therefore assume that labor costs are approximately equal across the two scenarios. We also do not consider the change in maintenance costs, as the only cost data available were not based on Mexico City data. We investigate the impact of modeling change in operation cost in section 11. In this analysis, we also consider publicity costs. Familiarizing users with a new system is an important step toward assuring that a bus rapid transit system is used to its full potential.

Cost of Infrastructure

The most significant cost associated with a new BRT system is the cost of the new infrastructure. For the Metrobús system, infrastructure costs include: stations, terminals, lane markers for separate lanes, reforestation[2], pedestrian bridges, public lighting, traffic signals, and equipment for fare collection [35, 36]. Unfortunately, when reporting cost of infrastructure data, the local government lumped most costs together under the heading “civil works” [35].

In order to convert the costs to U.S. dollars, the average exchange rate for 2005 of 10.89 pesos per dollar was used [37]. Total costs of infrastructure in pesos and dollars (adjusted for inflation for the year 2005) are listed in Table 9.1. We assume that no major repairs to the infrastructure will be necessary during the 10 years over which costs and benefits are calculated.

Construction costs are composed of capital costs and labor costs, each of which are taxed at different rates. Because it is not clear what proportion of these expenditures go to labor, and what proportion to capital, it is difficult to calculate the social value (excluding taxes). ETEISA, in a detailed analysis of the costs of a BRT system in Eje 10, estimated that taxes make up approximately 12.2% of total construction costs [2]. Therefore, to calculate the social value, we reduce the total cost by 12.2%.

Table 9.1. Total infrastructure costs for the Metrobús system in Insurgentes [35, 36].

Investment	**Pesos (2005)**	**U.S. Dollars (2005)**
Civil works, including stations, confined lanes, terminals, reforestation and pedestrian bridges	300,000,000	27,500,000
Public lighting	7,697,000	708,000
Traffic signals	9,851,000	904,000
Fare collection equipment	21,780,000	2,000,000
Total (including taxes)	339,328,000	31,160,000
Total social value	*297,862,000*	*27,352,000*

Cost of Vehicles

In addition to the new infrastructure costs above, new articulated buses were needed to provide service. Initially, RTP purchased 20 buses, and CISA purchased an additional 80. After operation began, and demand proved to be greater than expected, RTP converted 5 additional buses and CISA purchased another 4 buses. Metrobús has reported that the average cost of the articulated buses was $2.65 million pesos [9]. Assuming that this figure also took into account the converted RTP buses, the total cost was $235.85 million pesos. In order to calculate the pre-tax value, the total is reduced by 15%. Converted to dollars, the total cost for buses is $18.41 million U.S. dollars.

[2] Because of public concern about the number of trees on Insurgentes removed for the construction of the stations, the city government agreed to replant an equivalent number of trees in other areas in the city.

Presumably, in the baseline scenario some number of microbuses or buses would be replaced. However, because of the lack of data with which this cost could be calculated, we do not include it in the calculation.

Cost of Publicity

Though a small cost, adequate publicity to promote and explain the Metrobús system is an important part of its development as a viable alternative transportation option. Metrobús spends approximately 2% of its fares on publicity [38]. Given the total demand calculated in Table 6.4 and a fare of 3.5 pesos, Metrobús spends approximately $461,000 U.S. dollars on publicity, on an annual basis (Table 9.2).

Table 9.2. Total annual spending on publicity for the Metrobús system.

Concept	Value	Source
Total demand (annual)	71,760,000	Table 6.4
Fare (pesos)	3.5	[9]
Percent spent on publicity	2%	[38]
Total publicity costs (million pesos)	5.0	--
Total publicity costs (U.S. Dollars)	461,000	--

Cost of Fuel

Major changes in vehicle technology, like those associated with the introduction of the Metrobús system, cause changes in fuel consumption. Because fuel costs are an important component of total vehicular operating costs, we consider the change in fuel expenditure. As stated in section 3, it is appropriate to consider real costs to society, which do not include government subsidies or taxes. Because data on real costs of vehicle fuels were not available for Mexico, we calculate costs based on pre-tax cost of vehicle fuels in the U.S. Data on average annual fuel prices are published in the Energy Information Administration's (EIA) Annual Energy Review [39]. The EIA also publishes data the contribution of taxes to total fuel prices for gasoline and diesel fuels [40, 41]. Costs are calculated as the average for the two most recent years available, adjusted for inflation to 2005 [42].

The total change in fuel use by type is calculated using the methods in section 6. Total use of gasoline, liquid petroleum gas, gasoline and diesel decreased. After-tax average price of gasoline in 2003 and 2004 was 47 cents per liter [39]. Taxes made up 27% of total price in 2003, and 23% in 2004 [40]. The pre-tax average price of gasoline was 35 cents per liter (Table 9.3). For diesel, data on the contribution of taxes to total price was only available for January of 2006, when taxes represented 21% of the price at the pump, or 14 cents per liter [41]. Applying the absolute value of taxes in 2006 to annual mean prices in 2003 and 2004, the average pre-tax price of diesel was 31 cents per liter.

Determining the appropriate costs for liquid petroleum gas (LPG) and compressed natural gas (CNG) was more difficult. The EIA did not release data on the contribution of taxes to total price for these fuels. We assume that taxes do not make up a significant proportion of these fuels, as they are promoted as cleaner alternatives to typical vehicle fuels. The average consumer prices of LPG and CNG are listed in Table 9.3.

Table 9.3. Price per liter of vehicle fuels used in the Insurgentes corridor, in U.S. cents adjusted for inflation to the year 2005 [39-41]. The predicted change in consumption of these fuels and the total cost are also shown.

Fuel	**Cost (cents per liter)**	**Change in Consumption (liters)**	**Total Cost (USD)**
Gasoline	35.3	-5,323,000	-1,881,000
Diesel	31.5	-3,083,000	-970,000
CNG*	32.8	-151,000	-50,000
LPG	34.9	-2,246,000	-783,000
Total Cost			*-3,683,000*

*Units for CNG are m^3 rather than liters.

Total Costs

Total costs are summarized in Table 9.4. Costs in 2005 include the construction of the system, installation of the payment system, and purchase of new vehicles. Recurring annual costs include publicity and savings in fuel purchases. We assume that publicity began in the beginning of 2005, but that fuel savings only occurred during half of that year.

Table 9.4. Annual costs to society of the Metrobús corridor on Insurgentes.

Year	**Annual Costs (2005)**	**Annual Costs (2006-2015)**
Infrastructure	27,350,000	--
Vehicles	18,410,000	--
Publicity	460,000	460,000
Fuels	-1,840,000	-3,680,000
Total	44,380,000	-3,220,000

X. Benefit-Cost Comparison

In this section, the benefits of the Metrobús corridor on Insurgentes Avenue are compared to the costs. Travel time benefits are calculated in section 8, health benefits in section 6, and greenhouse emission benefits in section 7. Costs are calculated in section 9. Table 10.1 shows the annual monetary benefits by type, the annual costs, and the annual net benefits. The net present value of costs and benefits is shown using a discount rate of 7% [43]. The benefits to which monetary values were assigned are approximately 60% higher than the costs of the corridor. Evaluated in terms of greenhouse gas reductions, the corridor provided $44 of net benefits per ton of CO_2-equivalent ton of emissions reduced.

Table 10.1. Annual benefits and costs of the Metrobús system circulating on Insurgentes Avenue, million U.S. dollars, adjusted for inflation to 2005. The net present value is calculated using a discount rate of 7%.

Year	Travel Time Benefits (Million USD)	Health Benefits (Million USD)	Operational Costs (Million USD)	Net Benefits (Million USD)	Greenhouse Gas Reduction (Thousand tons CO_2 equivalent)
2005	0.7	2.0	43.3	-40.7	13.2
2006	1.3	3.7	-2.4	7.4	26.5
2007	1.3	3.6	-3.2	8.2	26.5
2008	1.3	3.5	-3.2	8.1	26.6
2009	1.3	3.3	-3.2	7.9	26.6
2010	1.3	3.1	-3.2	7.7	26.6
2011	1.3	2.9	-3.2	7.5	26.7
2012	1.3	2.7	-3.2	7.3	26.7
2013	1.3	2.6	-3.2	7.2	26.7
2014	1.3	2.4	-3.2	6.9	26.7
2015	1.3	2.1	-3.2	6.7	26.7
Net Present Value*	10.1	23.7	21.5	12.3	279.4

*Total greenhouse gas emissions reduction was summed rather than discounted.

When evaluating the cost-benefit analysis above, the reader should be aware of the conservative nature of the analysis. In this analysis, we assume that benefits such as time saved and vehicle kilometers traveled remain constant over the ten years modeled. However, it is likely that both benefits (relative to the counterfactual baseline) will increase in magnitude as congestion in Mexico City makes the Metrobús' confined corridors more attractive to commuters. In addition, only benefits which could be measured using available data were included in the analysis. A number of important benefits were not calculated or were not assigned a monetary value. We expect that some of these benefits may be substantial in an urban improvement investment like the Metrobús. Table 11.2 lists some of the benefits to that were not evaluated in this analysis.

Table 10.2. Additional benefits of Metrobús-Insurgentes that were not quantified in this analysis [Adapted from ref. 1].

Category	Description
Economic	More reliable product deliveries
	Increased economic productivity
	Increased employment
	Improved work conditions
	Savings on maintenance of public transportation vehicles
	Increase in reliability of public transportation

Category	Description
Social	More equitable access throughout the city
	Reduced accidents and injuries
	Increased civic pride and sense of community
Urban form	More sustainable urban form, including densification of major corridors
	Reduced cost of delivering services such as electricity, water and sanitation
Environmental	Reduced emissions from changes in vehicle speeds along Insurgentes
	Reduced noise

XI. Sensitivity Analysis

A cost-benefit calculation that models both human behavior and environmental health outcomes is subject to substantial uncertainty. In order to evaluate the importance of several major sources of uncertainty, we modify assumptions made in the primary analysis and reevaluate costs and benefits. First, the assumptions that are changed are discussed in turn. Then, in Table 11.3 the net present values of costs and benefits under the alternate assumption are presented. All costs and benefits in this section are in U.S. dollars, adjusted for inflation to the year 2005.

Travel time benefits grow at 3% per year

In the primary analysis, we do not account for increases in travel time benefits. However, it is likely that these benefits will grow between 2005 and 2015. First, as congestion increases in Mexico City, the travel time in public transportation on Insurgentes Avenue would likely have increased in the absence of the Metrobús. Therefore, as the baseline scenario deteriorates, the benefits of the Metrobús scenario increase. Second, the willingness to pay of public transportation users would likely increase in real terms, as economic growth causes their real salaries to increase. We use a growth rate of 3% to estimate the possible magnitude of these impacts. This increases the present value of time savings to \$11.6 million, an increase of \$1.5 million in total net benefits.

Particulate matter vehicle emissions are doubled

Particulate matter emission factors likely underestimate the total particulate emissions in both the baseline and Metrobús scenarios. First, Mexico City is located at extremely high altitude (2250 meters above mean sea level). At high altitude, particulate matter emissions are higher for diesel vehicles [44], and altitude is likely also a factor for gasoline vehicles. The U.S. EPA has estimated that diesel particulate matter emission factors increase by 47% at high altitude. However, the Mobile model does not account for this impact. Without a consistent way to adjust both diesel and gasoline particulate matter emission factors, we decided to use Mobile emission factors in our primary analysis. Second, particulate matter emissions in Mexican vehicles are likely higher than estimated by Mobile because of less than optimal maintenance practices. In order to determine the importance of the likely underestimate of particulate matter emissions in both the baseline and Metrobús scenarios, we double particulate matter emissions and reevaluate costs and benefits. Doubling particulate matter emissions increases the present value of health benefits to \$30.7 million dollars, an increase of \$6.5 million.

Eliminate benefits from mode change

In this analysis, we use survey data from August, 2005 to estimate the percent of Metrobús users that formerly used private vehicles. Because this was only two months after the service began functioning, equilibrium levels of ridership may not have been reached. In addition, we do not account for the opposite leakage, that is, we do not account for individuals who abandon public transportation along Insurgentes Avenue in favor of private vehicles or taxis. In order to test the impact of our assumptions, we calculate benefits taking into account only the technology change of public transportation vehicles that operate on Insurgentes Avenue.

Eliminating mode change benefits decreases total health benefits to \$22.2 million dollars, a decrease of \$1.5 million. In addition, the fuel savings due to mode change is no longer considered in this scenario. Therefore, the present value of costs increases to \$33.7 million, an increase in \$12.2 million. In this scenario, net benefits are negative, at a net loss to society of \$1.4 million.

Higher private vehicle speeds

This analysis does not account for decreased emissions due to higher speeds of vehicles that operate on Insurgentes Avenue. We chose not to include this benefit because adequate measured data on changes in average speed and fuel economy were not available. An analysis of greenhouse gas reductions attributable to Metrobús did estimate the change in greenhouse emissions from private vehicles operating on the corridor, using estimated changes in fuel economy [6]. The analysis found that of a total of 35.2 thousand tons of CO_2-equivalent emissions eliminated, over 46% resulted from the improvement in flow of private vehicles. In order to estimate the magnitude of this impact, we assume that calculated emissions benefits make up only 54% of the total emissions benefits. This increases the present value of health benefits \$20.4 million, and increases net present benefits to \$32.7 million.

Use Six Cities dose-response values

The magnitude of health benefits is sensitive to the choice of an epidemiologic study to estimate the impacts of exposure to fine particulate matter. Several cohort studies considering the impact of particulate matter on mortality are available, of which only the American Cancer Society (ACS) and Six Cities studies consider a general U.S. population [45, 46]. Though the ACS study considers a larger and more diverse population than the Six Cities study, the Six Cities study characterizes exposure to particulate matter better than the ACS study. The higher effects estimate reported by the Six Cities study may be caused by the improved exposure estimate, rather than chance occurrence in a smaller study population. We use the central effects estimates of the American Cancer Society (ACS) cohort study to estimate mortality impacts in our primary analysis (see section 6). In Table 11.3, we calculate health benefits using the concentration-response coefficient reported by the Six Cities study. This increases the present value of health benefits $7.5 million, and increases net present benefits to $19.8 million.

Use Mexican data to assign economic value to health effects

We derive willingness to pay (WTP) values for Mexicans in two ways: 1) by adjusting U.S. estimates for Mexican income levels [30, 47], and 2) using preliminary results of a contingent valuation study and hedonic wage study performed in Mexico [48, 49]. Using willingness to pay estimates for the Mexican population is preferable to adjusting U.S. estimates. However, only one study of WTP for health endpoints is available for Mexico, and WTP varies considerably among studies. In contrast, a larger body of evidence concerning WTP for health endpoints is available for Americans. In the primary analysis, we calculate benefits with adjusted U.S. estimates of willingness to pay. In Table 11.3, benefits are calculated with the results of the single Mexican study. This decreases the present value of health benefits and the net present value by $5.1 million.

Account for vehicle operation savings

Operational costs that may differ between the two scenarios include the use of lubricants and tires, and the costs of supplies and labor associated with general repairs. Eteisa calculated the social cost per kilometer of these operational costs for four types of vehicles: private cars, microbuses, buses, and articulated buses [2]. We used their values to estimate any change in operation costs (Table 11.1). The total cost is calculated from the change in vehicle kilometers traveled in Table 11.2. Because the calculated total savings is high, and the difference in operational costs was not measured, we did not include it in the primary estimate of costs. Accounting for vehicle operation savings decreases the present value of costs to $4.8 million, and increases total net benefits to $29.0 million dollars.

Table 11.1. Social cost per kilometer of operating four vehicle types (U.S. cents/km).

Vehicle Type	Private Car	Microbus	Bus	Articulated Bus
Lubricants	0.24	0.51	0.68	0.74
Supplies	2.41	3.17	4.30	5.63
Labor	0.92	1.80	2.03	1.52
Tires	0.62	2.20	2.56	4.33
Total	4.18	7.68	9.57	12.21

Table 11.2. Total change in operational costs (U.S. dollars per year).

Vehicle Type	Private Car	Microbus	Bus	Articulated Bus	Total
Change in VKT	-32,150,000	-4,270,000	-14,150,000	6,790,000	--
Lubricants	-80,000	-20,000	-100,000	50,000	-150,000
Supplies	-770,000	-140,000	-610,000	380,000	-1,140,000
Labor	-300,000	-80,000	-290,000	100,000	-570,000
Tires	-200,000	-90,000	-360,000	290,000	-360,000
Total	-1,340,000	-330,000	-1,350,000	830,000	-2,220,000

Varying the discount rate

There is considerable debate around the selection of an appropriate social discount rate. The U.S. government suggests using discount rates of 3% and 7% [43]. However, the Mexican Ministry of Finance evaluates policies with a discount rate of 12%. We use a discount rate of 7% in our primary analysis, and present results using 3% and 12% discount rates in Table 11.3. Because time savings and health benefits were constant over time or decreasing with time, varying the discount rate did not have an extremely large impact on these benefits. However, because capital costs are concentrated in the first year and cost savings are projected into the future, the net costs were sensitive to the discount rate used. Using a 3% discount rate increased net present value of benefits to $23.3 million, while a discount rate of 12% decreased net present value of benefits to $2.2 million.

Table 11.3. Sensitivity of cost and benefit estimates to alternate assumptions.

Scenario	Time Savings (Million USD)	Health Benefits (Million USD)	Operational Costs (Million USD)	Net Benefits (Million USD)	Greenhouse Gas Reduction (Thousand tons CO_2 equivalent)
Base case	10.1	23.7	21.5	12.3	279.4
Time benefits increase	11.6	23.7	21.5	13.8	279.4
Double PM emissions (B)	10.1	30.2	21.5	18.8	279.4
Eliminate mode change (C)	10.1	22.2	33.7	-1.4	148.6
Higher private vehicle speeds	10.1	44.1	21.5	32.7	517.4
Six Cities dose-response	10.1	31.2	21.5	19.8	279.4
Alternate health valuation	10.1	18.6	21.5	7.2	279.4
Vehicle operating savings	10.1	23.7	4.8	29.0	279.4
Discount rate 3%	12.1	27.8	16.6	23.3	279.4
Discount rate 12%	8.3	19.8	25.9	2.2	279.4

XII. Conclusions

The Metrobús corridor in Insurgentes is expected to provide social net benefits with a net present value of $12.3 million U.S. dollars, and 280,000 tons of CO_2-equivalent greenhouse gas reductions over 15 years. The result of positive net benefits is relatively robust to changes in underlying assumptions. Only by eliminating benefits from mode change can the net benefit calculation be negative. However, as the baseline calculation is conservative and omits many important social benefits, we believe the probability of negative net social benefits is very low. Specifically, we excluded a number of benefits for which measured values were not available, such as the change in fuel economy for general traffic along Insurgentes Avenue, time savings for public transportation users during non-peak hours, and the other social benefits listed in Table 10.2.

Expanding the Metrobús system to 33 other major roadways in Mexico City, as envisioned by the local government, would provide beneficial synergies. We expect that per-kilometer net benefits would be greater for a system of Metrobús corridors than they are for the single existing Metrobús corridor. As more areas in the city are served by high-quality public transportation, public transportation will become more attractive relative to private vehicles. This will increase the mode change effect observed in the current Metrobús corridor, increasing the environmental and economic benefits of the system.

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