AN EX-POST EVALUATION FRAMEWORK FOR BRT AND MRT IN MEXICO

A study on the impacts of Bus Rapid Transit and Mass Rapid Transit in Mexico City

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ABSTRACT

Rapid urbanization and motorization are causing sustainability issues in large metropolises around the world. These issues particularly manifest in congestion, reduced livability, inequality, environmental deprivation and productivity losses. Mass transit systems offer the potential to mitigate many of these effects through a more efficient transport system. Bus Rapid Transit (BRT) and Mass Rapid Transit (MRT) are the most well-known and popular mass transit solutions. Especially in developing countries these can provide an efficient alternative to low-capacity, unregulated informal public transport. However, the impacts of these systems on sustainability are largely unknown. A lack of ex-post evaluations causes a knowledge gap in whether expected impacts are in fact realized. Furthermore, no studies that compare the two systems exist. Therefore the objective of this thesis is to develop an ex-post evaluation framework to assess and compare the impacts of BRT and MRT systems in developing countries.

This framework consists of nine indicators, subdivided into the social, environmental and economic concepts of sustainability. The social indicators are equity and safety from accidents. The environmental indicators are climate change, air pollution and modal shift. The economic indicators comprise travel time savings, construction costs, operating and maintenance costs and revenues. Unlike conventional evaluation methods, this framework only monetizes the economic indicators, since it is difficult to express social and environmental impacts in monetary terms and also undesirable because this underrepresents them in the outcomes. In order to aggregate the individual indicators the flag model was applied, which standardizes the impacts using critical threshold values based on a literature study. Surveys were conducted among passengers to estimate direct effects (370 respondents per corridor) and among other travelers within the zone of influence to approximate indirect impacts (90 respondents per corridor). The ex-post evaluation framework was case-tested in Mexico City on the recently implemented Metrobús (BRT) line four and Metro (MRT) line twelve.

The results show that the Metrobús line performs better in terms of construction costs, operating and maintenance costs and modal shift. Meanwhile, the Metro displays a higher performance for equity, safety, travel time savings, revenues, air pollution and climate change. The aggregated outcomes suggest that the Metrobús performs better on economic and environmental indicators, while the Metro achieves more significant social impacts. Overall, both systems perform equally, although Metrobús performance is slightly higher. Furthermore, the standardized values indicate that the overall performance of both transit lines is slightly below the average of other impact evaluations. Monetary aggregation of the economic indicators suggests that the Metrobús line is economically more efficient, but that profitability is higher for the Metro line. However, a sensitivity analysis reveals that the Metro's profitability depends heavily on the value of time, while the Metrobús is also profitable for low values of time.

The analysis of only two transit lines is insufficient to settle the BRT or MRT debate. Nonetheless, it can aid the political decision-making process since it shows clear differences exist between the two systems in terms of indicator performance. The anticipated impacts of the selected transit system should match the political objectives of the transit line. In addition, inclusion of both BRT and MRT options in passenger demand studies further improves the attainment of political objectives. Furthermore, this evaluation framework is applicable and useful for the ex-post evaluation of other transit lines and provides a first step towards additional evaluations. Hence, it is recommended to apply this framework for the evaluation of the fifth Metrobús line in Mexico City and other recently implemented transit lines in Mexico. The acquired data will improve the critical threshold values and the comparability between systems. Additionally, this may provide a more definitive settlement of the BRT or MRT debate.

RESUMEN

En las grandes metrópolis del mundo, la urbanización y motorización provocan rápidamente problemas de sustentabilidad, que se manifiestan en congestión, habitabilidad reducida, desigualdad, degradación medioambiental y poca productividad. Los sistemas de transporte masivo pueden mitigar potencialmente estos problemas, dado que mejoran la eficiencia de los sistemas de transporte. Los transportes masivos más conocidos y más populares son el BRT y MRT. Especialmente en países en desarrollo, constituyen una alternativa eficiente al transporte público informal, caracterizado por su baja capacidad y la ausencia de regulación. Sin embargo, los impactos de esos sistemas son en gran parte desconocidos. Lo anterior se debe a una falta de evaluaciones ex post, que permiten conocer si se han realizado los impactos previstos. Además, no existe ningún estudio que compare los sistemas BRT y MRT. Por lo tanto, el objetivo de esta tesis es desarrollar una herramienta para evaluaciones ex post que evalúe y compare los impactos en sistemas de BRT y MRT en países en desarrollo.

Esta herramienta consta de nueve indicadores, subdivididos en sociales, medioambientales y económicos. Los indicadores son equidad, seguridad de accidentes (sociales), cambio climático, calidad del aire, cambio modal (medioambientales), ahorros de tiempo, costos de construcción, costos de operación y mantenimiento e ingresos de venta de boletos (económicos). Diferente a evaluaciones convencionales, esta herramienta solo monetiza los indicadores económicos, por la dificultad de expresar monetariamente los indicadores sociales y medioambientales. Para la agregación de los indicadores individuales se aplicó el modelo de la bandera. Esté modelo utiliza valores de límites críticos, basados en los impactos encontrados en otros estudios, para estandarizar los impactos. El caso de estudio de la Ciudad de México funcionó como prueba de la herramienta. Se aplicó la herramienta en línea cuatro del Metrobús (BRT) y en línea doce del Metro (MRT). Se realizaron encuestas a los usuarios para estimar los impactos directos y encuestas a no-usuarios en la misma área de influencia para aproximar los impactos indirectos.

Los resultados muestran a Metrobús con un mayor rendimiento para los costos de construcción, los costos de operación y mantenimiento y el cambio modal. El Metro tiene un mayor rendimiento para equidad, seguridad, ahorros de tiempo, ingresos de venta de boletos, calidad del aire y cambio climático. Los indicadores agregados indican que el rendimiento del Metrobús es más alto para los indicadores medioambientales y económicos y menor para los indicadores sociales. En general, el rendimiento es un poco más alto para el Metrobús. Además, los valores estandarizados sugieren que el rendimiento de ambas líneas es similar al promedio de los impactos de otras evaluaciones. La agregación monetaria muestra que la línea de Metrobús tiene una eficiencia económica mayor. Por otra parte la rentabilidad es más alta para el Metro. Sin embargo, el análisis de sensibilidad revela que la rentabilidad del Metro depende fuertemente del valor del tiempo, mientras que en Metrobús también es rentable con valores de tiempo bajos.

La evaluación de dos líneas es insuficiente para resolver la discusión sobre BRT y MRT. No obstante, la evaluación puede apoyar la toma de decisiones políticas, porque muestra que existen grandes diferencias entre los indicadores de ambos sistemas. Es importante que los impactos anticipados del sistema elegido correspondan con los objetivos políticos de la implementación. Además, se puede mejorar el logro de objetivos mediante la inclusión de opciones de BRT y MRT en los estudios de oferta y demanda. Asimismo, la herramienta es útil para la evaluación de otras líneas de transporte público. Por eso, se recomienda aplicar la herramienta para evaluar la línea cinco del Metrobús y otras líneas de transporte implementadas recientemente en México. Los datos adquiridos mejoran los valores de límites críticos y la comparación entre los sistemas. Además, los resultados de esas evaluaciones podrían resolver en definitiva la discusión sobre BRT y MRT.

EXECUTIVE SUMMARY

Rapid urbanization is, especially in developing countries, causing many people to migrate to cities to find income opportunities. Furthermore, cities cannot accommodate the large influx of new citizens, forcing many of them to reside in slums in the outskirts of large metropolises. Such slums lack access to many essential amenities, such as water, education, healthcare and employment and transport opportunities. This lack of opportunities results in large (income) inequalities, especially in less-developed countries. Urbanization in combination with rapid motorization also cause transport demand to increase enormously, while infrastructure provisions often lag, particularly in developing countries. Consequently, congestion is a major problem, with much time lost in traffic, impeding economic efficiency and development. This congestion causes many environmental issues as well, particularly air pollution and climate change. The transport sector is responsible for approximately 22.3% of total CO_2 emissions, of which 73.6% is emitted by road transport. Simultaneously, transport is responsible for the emission of harmful pollutant gases, such as carbon monoxide (CO) and particulate matter (PM), which is mainly evident in large metropolises.

In developing countries, congestion is for a large part due to informal public transport dominating the (public) transport market. As a result, many privately-owned vehicles offer transport services, often using easily navigable small buses or minivans. These services are often unsafe, polluting and overcrowded, but are still popular due to high frequency and coverage. Nonetheless, these services can provide an important complimentary feeder service to mass transit solutions. Mass transit systems have the potential to mitigate congestion by providing a more efficient movement of people. Mass Rapid Transit (MRT) has traditionally been the most popular mass transit mode. However, high capital investments hinder implementation in developing countries. To overcome these affordability issues for mass transit solutions, Curitiba (Brazil) introduced the Bus Rapid Transit (BRT) system in 1974. Bogotá's TransMilenio mimicked this system in 2000 and henceforth many, mainly Latin American, cities have followed suit. Capacities of full BRT systems approach those of MRT systems, while capital investments are ten to a hundred times lower. Furthermore, BRT provides a flexible and short-term solution to congestion problems. Nonetheless, BRT is still considered a second-hand alternative to MRT, particularly because BRT occupies scarce road space otherwise dedicated to cars.

One of the reasons that ambiguity about the effectiveness of BRT and MRT persists is that effects of BRT and MRT systems have only been researched minimally. Many studies evaluate one or a couple effects, but few conduct an extensive evaluation incorporating a wide range of effects. Especially once a project has been implemented little attention is given to the impacts and successfulness of a project. This study developed an ex-post evaluation framework of BRT and MRT systems in Mexico. This was done by creating a framework that includes non-monetized environmental and distributive social effects, but also monetized economic impacts. The framework is useful to compare the impacts of BRT and MRT systems. This research provides insights in the performance of both systems and how this performance differs. In order to test the ex-post evaluation framework, a case study is conducted in Mexico City. This city was chosen because of the developing country context and since it is one of the few cities that have implemented a BRT and a MRT system.

LITERATURE REVIEW

Cost-benefit analyses (CBAs) are the most popular ex-ante appraisal method. A CBA compares several project alternatives to a reference situation in which the project is not implemented. This comparison is based on direct and indirect impacts of the transport project. These effects are classified as costs (e.g. construction costs) and benefits (e.g. travel time savings). The most typical characteristic of CBA is that all effects are quantified and monetized. The latter is often done using a shadow pricing methodology, such as the value of time (VOT). This way, all costs and benefits are summed resulting in a net present value (NPV) of each project alternative.

The drawback of monetization is that social and environmental impacts are difficult to monetize. Even the estimation of non-monetized project effects is regarded extremely difficult for some impacts, particularly public transport projects. Another major shortcoming of CBA is that distributive effects are not taken into account and one person's can benefit can nullify the costs of a hundred others. In reality, decision makers are also interested in equity, which concerns the fairness of the distribution of effects. This concerns what is an ethically justifiable distribution, i.e. how much some are allowed to 'suffer' for the benefit of others. Furthermore, many ex-ante appraisals are based on unrealistic assumptions, resulting in optimism bias to ensure projects go ahead.

The main advantage of ex-post evaluations is that they provide information on actual impacts, which can be used to optimize the assumptions in ex-ante appraisal. The methodology is similar to CBA, but actual observations are used instead of predictions. The two main methodical issues of ex-post evaluations are causality and the evaluation timing. Causality relates to which extent the effects are endogenous or exogenous of project implementation. Short-term evaluation is easier than long-term evaluation, because exogenous effects are minimal. On the other hand, evaluating too early means not all effects may yet be observable.

Many studies were consulted to attain a comprehensive overview of impacts included in transport appraisal. The impacts most often included in transport evaluation are infrastructure costs (construction costs and operating and maintenance costs), user benefits (travel time savings) and externalities (air pollution, climate change, noise and accidents). However, distributional and equity impacts are also important in transport evaluation, because these provide vital information of who benefit from the project and if this is morally just. Furthermore, many ex-post evaluations and ex-ante appraisals only include direct (user) benefits and exclude indirect impacts on travelers who use a different transport mode within the same area.

CASE STUDY: MEXICO CITY

The Mexico City Metropolitan Area (MCMA) is a conglomeration of previously separate cities, often abbreviated to Mexico City. Its central part is the Federal District, but the city also comprises the states Estado de México and Hidalgo. Mexico City is situated in a former lake basin at 2,240 meters above sea level and is surrounded by several mountain ridges. Mexico City has a population of 21.1 million and is the nation's economic center, producing 27.2% of the national GDP. The Federal District is the main employment center and the Estado de México is more residential, resulting in unbalanced traffic flows within the city. Poverty is more widespread in the Estado de México (45.3%) than in the Federal District (28.5%). Income inequalities are also largest in the Estado de México, with a Gini-index of 0.436 compared to a Gini-index of 0.413 in the Federal District.

Mexico City is ranked amongst the most polluted cities in the world. The mountain ridges surrounding the city function as a barrier, containing many pollutants within the valley. High pollutant concentrations are primarily caused by transport, which consumes over half of Mexico City's energy and is responsible 70% of all pollutant emissions. This is aggravated by reduced engine efficiency due to Mexico City's high altitude. Furthermore, Mexico City's CO_2 emissions significantly contribute to global warming, with annual emissions of over 43 million tons, of which almost half is transport-based. However, due to old-vehicle replacement, cleaner fuels and mandatory use of catalytic converters, pollutant concentrations have decreased in recent years.

A total of 21.9 million daily trips are made in Mexico City. Public transport is the main transport mode, representing 70.9% of all trips. Low-capacity minivans and buses provide 78% of these public transport trips. Only a small fraction of 20.7% of all trips is made by car. Mexico City's

Metro network consists of twelve lines spanning 197 km, transporting 4.7 million passengers daily. A ticket costs US$ 0.37, although some social groups are exempt. The twelfth Metro line, inaugurated in 2012, is the focus of this study. This line was selected because it is the only Metro line that was implemented in recent years. This line has a length of 24.3 km, serves twenty stations, connects with four other Metro lines and transports 430,000 daily passengers, of which 158,000 transfer from other Metro lines.

In 2005 the first BRT corridor was implemented in Mexico City and named Metrobús. Currently, the Metrobús network comprises five lines with a total length of 105 km, transporting 855,000 daily passengers. The Metrobús fare is US$ 0.45. Implementation of the first Metrobús corridors was difficult, because existing operators feared losing income. To resolve this, operators were included in the planning and operation of the Metrobús lines. The fourth Metrobús line was selected for this study, because its recent implementation limits the causality problem described in the previous section. The line is 28 km long, serves 37 stations, connects with six Metro lines and three Metrobús lines and transports 59,344 passengers per working day. It is important to note that the Metrobús line is not a full BRT line, but an open BRT system. Except for the terminals, stops consist of platforms with on-board fare collection. Also, buses are non-articulated because they have to navigate narrow streets in the historic center. This significantly reduces the line's capacity and number of passengers. The service to and from the airport has a higher fare of US$ 2.25.

METHODS

This ex-post evaluation framework evaluates a total of nine social, environmental and economic impacts separately and monetizes only the latter. The evaluation includes both direct (users) and indirect (travelers within the zone of influence using a different transport) impacts. The social indicators included in the framework are equity and safety. Equity regards the fairness of the distribution of impacts. This is measured by the distribution of travel time savings along income groups. A Lorenz curve is plotted with the cumulative share of total trips ordered by income on the x-axis and the cumulative share of inverse previous travel times on the y-axis. Next, a Gini-index is calculated and the same is done for current travel times. This Gini-index represents the equality of the distribution of travel times along income, with positive values representing lower travel times for higher income groups and a positive value the reverse. The change in Gini-indices represents the equity impact. Safety is measured by the safety perception of respondents. The relative difference between current and previous safety perception characterizes the safety impact.

The environmental indicators are air pollution, climate change and modal shift. Air pollution concerns the reduction of CO, NO_x and PM_{10} emissions. Current and previous emissions are estimated using emission factors per trip differentiated per transport mode and the corresponding modal split within the zone of influence of the transit line. The relative change of each pollutant emission is then calculated and the average change represents the air pollution indicator. The climate change indicator is determined similarly, but only CO_2 emissions are included. The modal shift concerns the previous transport mode of passengers. Since the most interesting modal shift is from private vehicles, the summed modal shift from cars and taxis is considered.

The economic indicators are travel time savings, construction costs, operating and maintenance costs and revenues. Travel time savings are calculated using the difference between previous and current travel times. Following economic theory, the rule of half is applied, in which existing users enjoy full benefits and substituted users only half the benefits. Users shifting from other public transport modes are considered existing users, while users shifting from other modes are considered substituted users. The travel time savings are monetized using a value of time of US$ 3.76 per hour, based on 50% of the average income of US$ 1304 per month. An income-dependent VOT is also used to demonstrate the impact of an equity VOT. Construction costs are based on public accounts of the government of the Federal District. Operating and maintenance costs are based on payment per kilometer for Metrobús and on average costs per kilometer for Metro. Revenues are determined by multiplying the number of passengers by the fare, the fraction of passengers that is not exempt from the fare and the fraction of new passengers. To allow for comparison, construction costs, operating and maintenance costs and revenues are all expressed per kilometer of infrastructure.

Indicator	CTV_{min}	CTV	CTV_{max}
Safety	21.5%	34.9%	48.3%
Equity	-0.1%	8.6%	17.3%
Air pollution	-57.5%	-39.2%	-20.9%
Climate change	-58.4%	-42.0%	-25.6%
Modal shift	7.8%	10.9%	14.0%
Travel time savings	19.8%	26.4%	33.8%
Construction costs (per km)	$6.4M	$46.2M	$86.1M
Operating costs (per year per km)	$1.1M	$1.3M	$1.5M
Revenues (per year per km)	$0.5M	$1.1M	$1.7M

Table 1: Critical threshold values.

The economic indicators are aggregated into a NPV and B/C ratio using a discount rate of 12% and project horizon of fifteen years. Furthermore, the VOT is increased along GDP growth. Also, a sensitivity analysis of the NPV is conducted in which the VOT is varied. Additionally, social, environmental and economic indicators are evaluated using the flag model. This model uses critical threshold values (CTVs) to evaluate the performance of indicators. These CTVs are based on studies evaluating similar impacts. It is important to note that most studies only include direct impacts. A minimum, average and maximum CTV are calculated based on the average and standard deviation, see Table 1. For benefits, a green flag is attributed to indicators values above the maximum, an orange flag for values between the average and maximum, a red flag for values between the average and minimum and a black flag for values below the minimum. For costs, the reverse holds. Based on the CTVs, standardized values ranging between -2 and 2 are calculated. For each indicator group, the standardized values are averaged to determine the standardized outcome and corresponding flag.

The data for the ex-post evaluation was collected using surveys among passengers and other travelers within the zone of influence using a different transport mode. A total of 369 surveys among Metrobús passengers and 373 surveys among Metro passengers were conducted. Among the other travelers a total of 104 surveys for Metrobús and 78 surveys for Metro were conducted. The number of surveys among other travelers is lower because impacts were expected to be smaller. The passenger survey results were expanded according to boarding station and the surveys among other travelers were expanded according to transport mode.

RESULTS AND DISCUSSION

The equity improvement is 31.3% for Metrobús and 39.8% for Metro. Hence, equity impacts are larger for the Metro line. This difference is especially caused by larger direct impacts for the Metro. Furthermore, the values of the Gini-indices are close to zero, suggesting that the distribution of travel times over income groups is very equal. This means that travel times are distributed very evenly over income groups. Furthermore, even small changes in the distribution have significant impacts on the indicator value, so the results are very sensitive to inaccuracies.

The direct and indirect safety impacts are larger for the Metrobús than the Metro. However, the total safety impact is larger for Metro (29.6%) than Metrobús (23.4%). This is because the fraction of Metrobús user trips represents only 9.7% of all trips within the zone of influence, while Metro user trips are 40.0% of all trips. Hence, the direct impacts have a more significant impact on the total impacts. Another noteworthy result is that the safety perception of Metrobús users is higher than the safety perception of Metro users. This is interesting, because generally MRT systems are considered safer than BRT systems, which still have conflicts with other traffic flows. A reason for the difference can be that respondents (subconsciously) included on-board safety in their response.

Both pollutant and CO_2 emission reductions are higher for the Metro line (29.6% and 22.8%) than the Metrobús line (12.3% and 4.9%). Also absolute emission reductions are significantly higher for the Metro line, representing around 0.3% of total transport emissions in Mexico City, compared to only 0.02% for Metrobús. This difference has three main causes. First of all, only mobile emissions are included so point emissions resulting from energy production for the Metro are excluded. Secondly, even though the modal shift from private vehicles is higher for Metrobús, the higher modal shift from low-capacity public transport has a larger impact on the results. Thirdly, the size of the modal shift is larger for Metro, because of the higher passenger numbers.

The modal shift from private modes is higher for Metrobús (14.3%) than Metro (7.5%). This is mainly caused by a difference in the taxi modal shift, which makes sense since the Metrobús line serves the airport and city center, two areas that typically have a higher taxi use. Furthermore, the average income of Metrobús passengers is almost double the average income of Metro users. Hence, passengers are more likely to be able to afford a taxi as alternative transport mode. This lower income also explains why the higher modal shift from low-capacity public transport is higher for Metro (63.7%) than Metrobús (40.5%). Furthermore, for the Metrobús line a high modal share from the Metro occurs (39.4%).

The travel time savings are shown in Table 2. Both in absolute and relative terms the travel time savings are larger for the Metro line than the Metrobús line. This is mainly because the fraction of users of the total population, which is much higher for the Metro line than the Metrobús line. Therefore, the higher direct travel time savings of the Metro have a larger impact on the total savings. Furthermore, average user travel times are significantly higher for the Metro, resulting in larger direct monetary impacts if the same relative impact is achieved. In fact, the relative direct travel time savings are larger for the Metrobús, but the larger number of travelers and higher absolute travel times results in higher monetized travel time savings for the Metro.

Transit line	Daily trips	TTS per trip (min.)	TTS	Annual TTS (hrs.)	Annual TTS (US$)	Direct TTS	Indirect TTS	% Direct TTS of total
Metrobús	609,948	6.6	11.1%	19,463,945	$73,203,897	34.7%	9.1%	24.5%
Metro	1,343,717	15.9	21.7%	103,655,935	$389,849,970	27.1%	15.6%	66.6%

Table 2: Travel time savings.

Construction costs per kilometer are much higher for Metro (US$ 65.9 million) than Metrobús (US$ 1.5 million). This is not surprising since rail infrastructure is generally ten to a hundred times higher than BRT infrastructure. However, also compared to other BRT lines, the Metrobús is cheap. Since it is not a full BRT, significant savings were made. The Metro line is less expensive than the average of other MRT lines. However, most of these MRT lines are located in developed countries, where labor costs and thus construction costs are higher. Operating and maintenance costs are also much higher for Metro (US$ 1.7 million per kilometer per year) than Metrobús (US$ 178,380 per kilometer per year. Operating and maintenance costs per passenger are more similar; US$ 0.28 for Metrobús and US$ 0.30 for Metro. These costs are also below the ticket price. However, overhead costs of the system's organization are not taken into account. Revenues are higher for Metro (US$ 2.0 million per kilometer per year) than Metrobús (US$ 267,992 per kilometer per year). This is not surprising since daily ridership is over ten times higher. Furthermore, these revenues are higher than the operating costs, indicating an operating profit.

Table 3 shows the results of the flag model. The color of the indicator cell represents the attributed flag. The Metro performs better on six indicators, while the Metrobús is superior for three indicators. Indicator aggregation shows that the Metrobús performs better on economic and environmental indicators, while the Metro performs better on social indicators. Overall, both systems perform similarly, although Metrobús performance is a little higher. Furthermore, the standardized values suggest that both systems perform almost equal to the averages found in literature. However, the CTVs are based on studies which often only include direct impacts, while this study also regards indirect impacts. Hence, the attributed flags portray a more negative performance than the two lines actually realize. Nonetheless, the comparison between the two lines is solid, because this affects the evaluation of both lines equally.

	Indicator	Abbr.	Metrobús Indicator value	Metrobús Standardized value	Metro Indicator value	Metro Standardized value
Economic	Travel time savings	TTS	11.1%	-2.00	21.7%	-0.64
	Construction costs	CON	$1,468,890	1.12	$65,853,454	-0.49
	Operating & maintenance costs	OM	$178,380	2.00	$1,733,957	-2.00
	Revenues	RE	$267,992	-1.34	$2,024,209	1.49
	Economic	**EC**	-	**-0.05**	-	**-0.41**
Social	Equity	EQ	31.3%	2.00	39.8%	2.00
	Safety	SA	23.4%	-0.86	29.6%	-0.40
	Social	**SO**	-	**0.57**	-	**0.80**
Environmental	Air pollution	POL	-12.3%	-1.47	-29.6%	-0.53
	Climate change	CC	-4.9%	-2.00	-22.8%	-1.17
	Modal shift	MS	14.3%	1.10	7.5%	-1.09
	Environmental	**EN**	-	**-0.79**	-	**-0.93**
	Overall	**OV**	-	**-0.09**	-	**-0.18**

Table 3: Overview of flag model and corresponding flags for all indicators for Metrobús and Metro.

Aggregation of economic indicators shows a NPV of US$ 541 million and a B/C ratio of 8.48 for Metrobús, compared to a NPV of US$ 1.4 billion and B/C ratio of 1.77 for Metro. Hence, the Metro line is more profitable, while the Metrobús line has a higher economic efficiency. For the Metro, this profitability mainly depends on travel time savings, since discounted construction, operating and maintenance costs and revenues accrue to US$ -1.6 billion, compared to only US$ -25 million for Metrobús. A sensitivity analysis of the VOT confirms this, since it reveals that the profitability of the Metro depends heavily on the VOT, while the Metrobús line is profitable for low values as well. Hence, the profitability of the Metro is uncertain. The Metrobús line, on the other hand, is profitable irrespective of the VOT.

CONCLUSIONS AND RECOMMENDATIONS

This study ex-post evaluated Mexico City's fourth Metrobús line and twelfth Metro line using nine indicators. The results show that the Metro has higher impacts for the equity, safety, air pollution, climate change, travel time savings and revenues indicators. Meanwhile, the Metrobús performs superior for construction costs, operating and maintenance costs and modal shift. Indicator aggregation indicates that both lines perform similarly, but the Metro is better for social indicators and the Metrobús for economic and environmental indicators. Furthermore, the Metrobús has a higher economic efficiency, while both projects are profitable.

These results are useful for future planning of mass transit systems. System selection should be based on the political objectives and which system's impacts match these best. In terms of large environmental impacts the Metro is preferable, as well as for safety, equity and travel time impacts. On the other hand, the Metrobús is preferable to implement a low-cost mass transit system that results in a significant modal shift from private modes. Furthermore, the study shows that the transit line's demand is very influential on the impacts. Currently, supply and demand studies are conducted after the system has been selected. Therefore, it is recommended to include both BRT and MRT systems in such studies.

The most important limitation of this study is that the Metrobús line is not a full BRT line. Thus, capacity and demand are lower and consequently impacts are smaller than they would have been for a full BRT line. Hence, it cannot be concluded that in general the Metro has, for example, higher emission reduction impacts. It is therefore recommended to conduct an ex-post evaluation of the recently implemented full BRT Metrobús line five. Also, although it provides a first step towards additional ex-post evaluations, the evaluation of two transit lines is not sufficient to settle the debate on BRT or MRT. Hence, since many Mexican cities have implemented BRT systems in recent years it is recommended to apply this methodology to conduct ex-post evaluations of these systems. Some adaptations will also allow for evaluation in other Latin American and developing country contexts. The outcomes of these studies are useful to improve the CTVs of the flag model. Additionally, this can provide more definitive conclusions on differences in impacts of BRT and MRT systems.

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CHAPTER 1. INTRODUCTION

This chapter provides an introduction to the research topic. First, a concise background of the problem addressed is given. From this background follows the purpose of this research. Finally, a reading guide is provided. This reading guide helps readers to find the parts of this thesis that are of main interest to them.

1.1 BACKGROUND

Since 2010 over half of the world's population is living in urban areas. Urbanization is still increasing, especially in developing countries, where large numbers of people move to cities to find income opportunities. As a result, 70% of the world's population is expected to live in urban areas by 2050. Additionally, developing countries are becoming increasingly motorized. The expanding urban population and motorization cause congestion problems in rapidly expanding cities (UN-Habitat, 2012). These trends significantly affect the livability of cities, manifesting especially in social segregation, environmental deprivation, economic inequalities and productivity losses. The concept of sustainable development focuses on overcoming these issues. The essence of this concept is that present needs are met without compromising the ability to meet future needs. This is done by focusing on the interaction between environmental, social and economic aspects in (policy) development. (WCED, 1987).

One of the major environmental concerns is the effect of climate change on the way of everyday life. Increasing greenhouse gas (GHG) emissions, of which carbon dioxide (CO_2) is the most important, are expected to result in rising sea levels and more extreme weather patterns (increased drought and heavier precipitation), among other effects (UN-Habitat, 2012). The majority of these emissions is caused by the most developed countries. Ironically, especially developing countries are prone to the effects, because of vulnerable locations of cities and limited adaptive capabilities (UN-Habitat, 2011). The transportation sector is responsible for approximately 22.3% of total CO_2 emissions, of which 73.6% is emitted by road transport. Meanwhile, fuel demand is increasing and emissions are expected to keep rising (IEA, 2012). Even in optimistic scenarios, which incorporate major mitigation policies, transport's CO_2 emissions are expected to increase by 40% between 2007 and 2030 (ITF, 2010). Simultaneously, transport is responsible for the emission of harmful pollutant gases, such as carbon monoxide (CO) and particulate matter (PM), which is mainly evident in large metropolises (UN-Habitat, 2012).

This development is aggravated by massive migration to cities, which cannot accommodate the large influx of new citizens, forcing many of them to reside in slums in the outskirts of large metropolises. Such slums lack access to many essential amenities, such as water, education, healthcare and employment and transport opportunities (OECD, 2011a). This lack of opportunities results in large (income) inequalities, which especially manifest in urban areas in less developed countries (OECD, 2011b). Urbanization also causes transport demand to increase enormously, while infrastructure provisions often lag, particularly in developing countries. Consequently, congestion is a major problem, with much time lost in traffic, impeding economic efficiency and development (UN-Habitat, 2012).

In developing countries, this congestion is for a large part due to informal public transport dominating the (public) transport market. No entry barriers exist, which leads to many privately-owned vehicles offering transport services, often using easily navigable small buses or minivans (Ardila, 2012). These services are often unsafe, polluting and overcrowded, but are still popular due to high frequency and coverage (Cervero and Golub, 2007). Furthermore, they often resist proposals to increase the efficiency of the transport market. As a result, implementation of more efficient mass transit systems is often delayed. Nonetheless, these services can provide an important complimentary feeder service to mass transit solutions (Hidalgo and Carrigan, 2010).

Such mass transit systems have the potential to mitigate congestion by providing a more efficient movement of people than private vehicles and informal public transport. Mass Rapid Transit (MRT) has traditionally been the most popular mass transit mode. Particularly (Western) European, North American and Asian cities have implemented such systems. However, high capital investments hinder implementation in developing countries. To overcome these affordability issues for mass transit solutions, Curitiba (Brazil) introduced the Bus Rapid Transit (BRT) system in 1974 (Wright and Hook, 2007). Bogotá's TransMilenio mimicked this system in 2000 and henceforth many, mainly Latin American, cities have followed suit. The World Bank recommends BRT as appropriate infrastructure for developing countries (Timilsina and Dulal, 2011). Capacities of full BRT systems approach those of MRT systems, while capital investments are ten to a hundred times lower (Wright and Hook, 2007). Furthermore, BRT provides more flexible and short-term solutions to congestion problems (Deng and Nelson, 2013). Nonetheless, BRT is still considered a second-hand alternative to MRT, particularly because BRT utilizes scarce road space otherwise dedicated to cars (Hidalgo and Gutiérrez, 2013).

1.2 RESEARCH PURPOSE

One of the reasons that ambiguity about the effectiveness of BRT and MRT persists is that effects of BRT and MRT systems have only been researched minimally. Many studies evaluate one or a couple effects, but few conduct an extensive evaluation incorporating a wide range of effects. For example, Keeling (2013) suggests research is required on the economic impacts of BRT. Furthermore, projects are regularly appraised ex-ante, but ex-post evaluations are rarely carried out (Knudsen and Rich, 2013). Nevertheless, ex-post evaluations are an important part of successful policy implementation (HM Treasury, 2003). In developing countries the lack of ex-post evaluations is even more evident, while ex-ante appraisal is often only carried out once a project has already been planned.

Problems within transport evaluation also persevere. Cost-benefit analyses (CBAs) have a financial approach and only evaluate projects on their economic performance, monetizing all effects. However, it is difficult to put a price on environmental and social impacts (Mouter et al., 2013). Furthermore, distributive effects are often completely left out (Mouter, 2012). Additionally, due to the utilitarian approach of CBA, high-income groups are more influential on results than low-income groups (Wee, 2011). As a result of these limitations, CBAs can have a positive outcome, even though only a small minority benefits. Also ex-post evaluations are not without methodological drawbacks. The major drawback is the causality, because not all observed effects are necessarily the result of the project. Hence, it is uncertain which effects are endogenous and which are exogenous (Berveling et al., 2009). This directly relates to the second issue, which is the evaluation timing, since short-term evaluations limit the causality problems, while long-term evaluations are preferable because effects are better observable (Annema et al., 2012). Short-term evaluations are conducted within one to two years after implementation and include effects such as travel time savings, whereas long-term evaluations are conducted after approximately ten years and focus on other impacts such as land use effects.

Concluding, a lack of extensive evaluations of BRT and MRT systems exists, particularly using ex-post evaluations. Furthermore, current evaluation methodologies encounter some problems, especially for the developing country context. For example, poverty is a major issue in large developing cities, but distributive effects are often ignored in evaluations, while this is of key importance in this context. This research therefore aims at developing an ex-post evaluation framework of BRT and MRT systems. However, due to time restrictions and contextual differences, this framework is only applicable to the Mexican context, since Mexico City is chosen as location for the case study. This city is selected because of the developing country context and since it has a BRT and a MRT system. The framework includes non-monetized environmental and distributive social effects, but also monetized economic impacts. Hence, the evaluation incorporates all three concepts of sustainability. This framework is useful to compare the impacts of BRT and MRT systems. However, the research does not aim to definitively settle the debate between BRT and MRT systems. Nonetheless, the research can provide insights in the performance of both systems and how this performance differs. Furthermore, it provides a first ex-post evaluation that incorporates both BRT and MRT systems.

1.3 READING GUIDE

This thesis is divided into eight chapters. After this first introductory chapter, the second chapter discusses the research design. This chapter introduces the research objective and explains what this research aims to accomplish. In order to clearly outline the research, several research questions are formulated. Finally, this chapter elaborates on the research methodology that is applied in the rest of this thesis.

The third and fourth chapters provide an overview of the literature that was studied for this research. The third chapter regards the theoretical framework that is used to develop the research methodology. This literature review focuses on ex-ante appraisal and ex-post evaluation methods and the problems encountered in their application. Furthermore, information is given on indicators used in other studies, and how these indicators are evaluated and aggregated. Finally, this chapter offers some insights in the theory of survey design. The fourth chapter focuses on sustainability and transportation in Mexico in general and Mexico City in specific. Also, Mexico City's MRT system and BRT system are introduced, putting a distinct focus on the two transit lines that are evaluated in this study. These two chapters are of particular interest to gain insights in the background of the issues addressed in this study.

Chapter five regards the methodology of this research. This chapter outlines the evaluation framework that is applied to evaluate the BRT and MRT lines. Furthermore, the indicators used within the framework are selected and the techniques used to calculate these are elaborated on. Additionally, the aggregation method and sensitivity analysis is explained. Finally, this chapter discusses how the required data is collected. This chapter is especially interesting to gain insights in how the results were achieved.

The results from the application of the methodology are presented in chapter six. This chapter merely describes the results and does not discuss its implications. All indicators are presented individually, but this chapter also provides the results of the indicator aggregation, as well as the main findings from the interviews. Chapter seven interprets the results presented in chapter six. This chapter relates the individual indicator performance to values found in literature. Furthermore, individual indicators of the BRT and MRT line are compared and discussed. Additionally, the aggregated indicators are compared. Based on this, a conclusion can be drawn on which of the systems performs better in general and in which area specifically. This chapter also compares the performance of both lines to the initial policy objectives and Mexico City's political context. Finally, some limitations of the research are discussed. These two chapters are of particular interest for readers that are interested in the outcomes of the research.

Finally, the eighth chapter concludes on the findings of this research. This chapter provides the most important conclusions that can be drawn from this research. Furthermore, the most important recommendations that follow from these conclusions are given, as well as recommendations for future research in the same field.

CHAPTER 2. RESEARCH DESIGN

The introduction gave the rationale for this research. This chapter discusses how this research is designed. First, the scope of the research is addressed, focusing especially on the location of the case study. Secondly, the research objective is set. Based on this research objective, several research questions and corresponding sub-questions are defined. Finally, the research methodology to answer these questions and to achieve the research objective is elaborated on.

2.1 SCOPE OF RESEARCH

The introduction shows that transport project evaluation is conducted on a regular basis. However, most research focuses on ex-ante appraisal and monetary evaluations. Meanwhile, ex-post evaluations are carried out minimally and especially social indicators focusing on distributional effects are often disregarded. Furthermore, for developing countries, BRT and MRT systems are the two main mass transit solutions. This research therefore focuses on ex-post evaluating a MRT and a BRT line, in a developing country context. For this purpose, Mexico City has been selected as the location of the case study. This city has been selected because it has a MRT system, the Metro, and a BRT system, the Metrobús. Also, for both systems new lines have recently been implemented. Besides, Keeling (2013) suggests that additional research on mobility is required for megacities, such as Mexico City, particularly since poorer segments of the population are concentrated in distant suburbs. This makes Mexico City a suitable location to test the ex-post evaluation framework developed in this research.

An important aspect of the evaluation is to select suitable transport lines. New Metrobús lines were implemented in 2005, 2008, 2011, 2012 and 2013 (ALC-BRT and EMBARQ, 2013). Since ex-post evaluation should typically take place one to five years after implementation (see section 3.3.1), only the third and fourth Metrobús lines comply. For a relatively new system not all effects may yet be attained. On the other hand, the later the evaluation is conducted, the more exogenous effects distort the analysis and causality issues occur. This latter problem is considered more troublesome for the analysis, which is why Metrobús line four is selected for the BRT evaluation. Mexico City's Metro has only expanded by one line since 1999; in 2012 the twelfth metro line was completed (Ciudad de México, 2013a). Hence, this is the only suitable Metro line to analyze, because exogenous effects are too large for other lines. Metro line twelve runs from south of the city center to the southeast of the city.

2.2 RESEARCH OBJECTIVE

Based on the introduction and the scope of the research, the following research objective is defined:

Develop and apply an ex-post evaluation framework to assess and compare the impacts of BRT and MRT systems in Mexico

This objective consists of several aspects that are conducted during the research. First of all, an ex-post evaluation framework is developed, which is applicable to both BRT and MRT systems and relevant for transport-related issues in Mexico. To do so, a literature study on where and how several appraisal methodologies are used to evaluate transport projects is executed. Also, the problems encountered in these methodologies are discussed to improve the framework. Based on this, suitable indicators are selected that are relevant for BRT and MRT systems and Mexico City. Secondly, the developed framework is applied to the cases of Metrobús line four and Metro line twelve. Thirdly, the outcomes of the evaluation for Mexico City's Metrobús and Metro are compared. This comparison focuses both on the overall outcome, but also on specific indicators, because some indicators have to fulfill a minimum threshold to be (politically) acceptable.

2.3 RESEARCH QUESTIONS

In order to achieve the research objective, several research questions need to be answered. The research questions and a brief explanation are given below.

1. *How are impacts of transport projects evaluated?*
   This research question mainly consists of a literature study on current practice in appraisal and evaluation methodologies in different contexts. Part of the study focuses on cost-benefit analyses (CBAs), but ex-post evaluations are addressed as well. The focus is on the evaluation of transport projects, and a range of countries where these are applied is discussed. Also, the experience with the application of these methods is interesting, because this provides insights in problems that are encountered. If problems are encountered repeatedly, this information can be used to adapt the framework to overcome these issues.
   The main goal of this research question is to gain insights in the type of indicators that are used in transport project appraisal. This is used as input for the development of the framework that will be applied to Mexico City. Furthermore, the incorporation of different locations will yield comprehension of which indicators are applicable in which situation. For example, one can expect equality indicators to be of higher importance in cities with great income disparities, but less so in cities where incomes are already relatively equal. Additionally, the problems identified are used to adjust the framework for this research. For example, literature may indicate that certain indicators are often left out, difficult to measure, contain large uncertainties etc. Also the way indicators are quantified is investigated, especially focusing on if and how indicators are monetized. Finally, the way in which indicators are aggregated is studied. Chapter three provides an overview of the literature on transport project evaluation.

   Sub-questions:
   a) *Where are appraisal and evaluation methodologies applied for transport projects?*
   b) *How are these methodologies executed?*
   c) *What problems are encountered in these methodologies?*
   d) *Which indicators are included in the appraisal and evaluation of transport projects?*
   e) *What methods are applied to aggregate indicators?*

2. *How can the impacts of Mexico City's Metro and Metrobús be evaluated?*
   The main goal of this research question is to develop the evaluation framework. First of all, the political context of Mexico City is investigated. This concerns both sustainability policies and the transport system in general. Based on the previous research question a suitable evaluation framework for Mexico City can be developed. This comprises a description of underlying assumptions of the framework and the evaluation steps. Furthermore, a suitable set of indicators for this framework is selected. The relevance of indicators for the case of Mexico City, based on the first sub-question, is taken into consideration for this. For example, social indicators may be more important in Mexico than in the Netherlands. How these indicators are evaluated is also part of this research question. Additionally, the necessity of monetizing indicators is discussed. Finally, this research question includes the aggregation of the individual indicators. Chapter four discusses the Mexican context and chapter five the evaluation framework that is applied to Mexico City.

   Sub-questions:
   a) *What is sustainability and transport context in Mexico City?*
   b) *What type of evaluation framework is applied for Mexico City?*

c) *Which indicators are used in the evaluation framework?*
d) *How are these indicators evaluated?*
e) *How is the data required for the evaluation collected?*
f) *How are the indicators aggregated?*

3. *What are the outcomes of the evaluation of Mexico City's Metrobús and Metro?*
The application of the evaluation framework developed in the previous question results in the outcomes of the evaluation. These outcomes are both given per individual indicator, but also for the aggregated indicators. The latter provides a more general overview of the impacts of the transit line. Furthermore, the outcomes are compared to the values that were expected beforehand. These expectations are based on the effects found in other literature studying the effects of transport projects. Chapter six elaborates on the outcomes of the evaluation framework.

Sub-questions:
a) *What are the outcomes of the individual indicators?*
b) *What are the outcomes of the aggregated indicators?*
c) *How do these outcomes compare to expected values?*

4. *How do the outcomes of the Metrobús and Metro compare?*
This research question compares the outcomes of the Metrobús line and the Metro line. This can contribute to the academic discussion on the effectiveness of the two transit systems. It is interesting to discuss for which indicators both systems perform similarly and for which differences exist. This is also discussed on an aggregated level. The aim of this research question is not only to compare the outcomes, but also to pinpoint specific differences in performance. This gives insights in which of the two systems can be best implemented in which case. A comparison of the outcomes with the policy objectives set before implementation is also made. This evaluates if initial expectations have been meet. Finally, a comparison with the expected performance by policy makers is made. This gives insights if they have the correct view of the transit line's impacts. Chapter seven discusses these comparisons.

Sub-questions:
a) *How do the individual indicators compare?*
b) *On an aggregated level, how do the Metrobús and Metro line compare?*
c) *Which transport system is preferable for which policy objective?*
d) *Does the performance meet the policy objectives of the transit lines?*
e) *How does this compare to the expected performance by policy makers?*

2.4 RESEARCH METHODOLOGY

To conduct this research, a research methodology has been developed. The goal of this research methodology is to answer all the research questions to achieve the research objective. A research model has been developed to graphically display the steps in the research, see Figure 2-1. This research model consists of four parts: the theoretical framework, the evaluation framework, the case study and the results. The theoretical framework concerns the literature study that is conducted for this research. This forms the theoretical basis of the research and aims to answer the first research question and its sub-questions. The evaluation framework refers to the framework that is developed to evaluate the impacts of BRT and MRT systems. This part's goal is to answer the second research questions and its sub-questions. The theoretical framework is the basis for the evaluation framework. The third part is the case study of Mexico City's Metrobús line four and Metro line twelve. This consists of the data collection required to evaluate the impacts. The main goal of this part is to acquire data to get results. The final part of the research is the results. The results are based on the data collected for the case study and the evaluation framework developed. This part aims at answering the two final research questions and all its sub-questions.

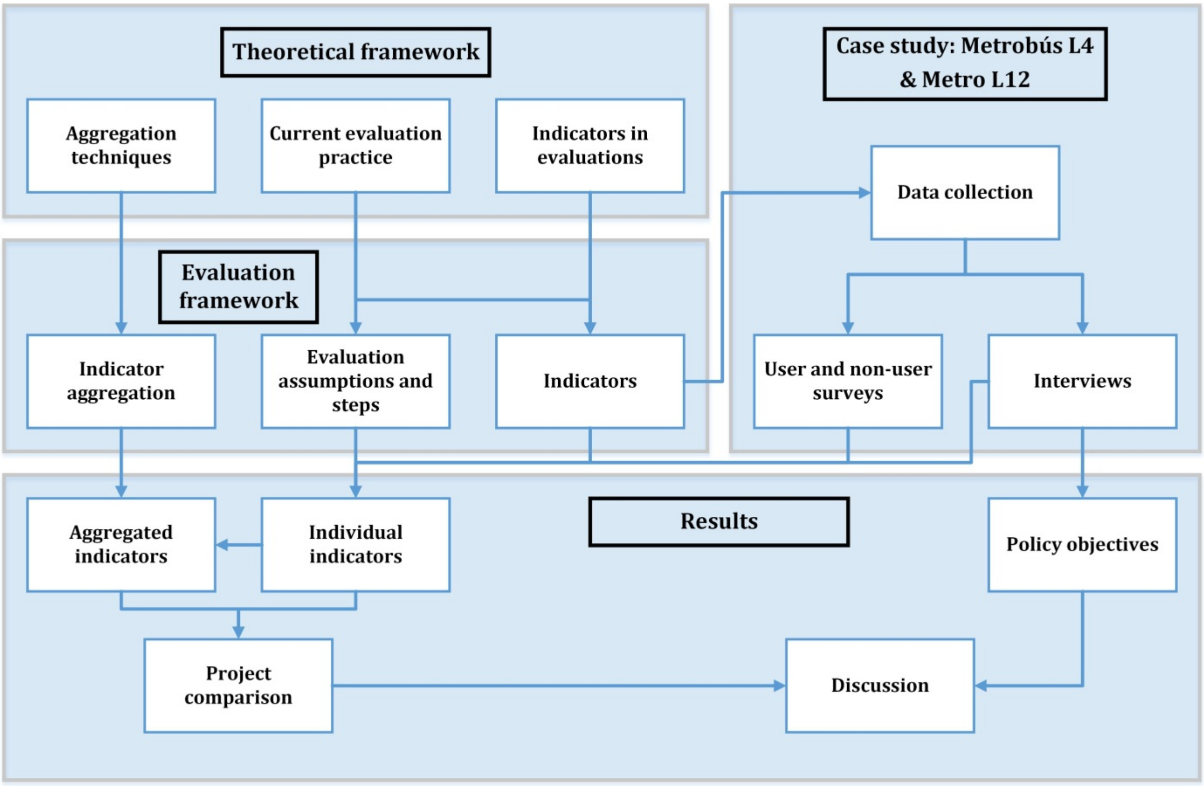

Figure 2-1: Research model.

CHAPTER 3. THEORETICAL FRAMEWORK

This chapter discusses the relevant literature for the research. The focus is on methodologies to evaluate the performance of transport systems. First of all, relevant principles of sustainable transport and transport planning are explained. Secondly, an overview of a popular ex-ante appraisal methodology is discussed: cost-benefit analysis. Thirdly, ex-post analysis methodologies are addressed. Fourth, the indicators for appraisal frameworks that are used in the previously discussed methodologies are identified. Fifth, the criteria used for transport evaluation are mentioned. Sixth, a brief introduction is given on how a survey can be designed effectively. Finally, based on the literature review some conclusions that are useful for the methodology chapter are given.

3.1 SUSTAINABLE TRANSPORT AND TRANSPORT PLANNING

This section discusses basic principles of sustainable transport and transport planning. First of all, some literature on sustainable development is discussed. Secondly, a more distinct focus is put on sustainable transport. Finally, public transport in developing countries is addressed.

3.1.1 SUSTAINABLE DEVELOPMENT

The concept of sustainable transport is strongly intertwined with sustainable development, which provides a more general description. This was thoroughly studied by the Brundtland Commission. This UN Commission studied the effects humanity has on its environment and has set guidelines on how to address this issue. They defined the concept of sustainable development as follows:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- *the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and*
- *the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future need." (WCED, 1987, p. 41)*

This definition highlights that sustainability does not only refer to environmental goals, but should put a distinct focus on environmental, social and economic issues and the interaction between the three (WCED, 1987). Hence, effects should always be discussed in harmony, since positive economic effects may impair the environment's ability to meet future generations' needs, or vice versa.

In terms of environmental sustainability, climate change is an issue increasingly recognized in academic literature. Especially the use of fossil fuels is of growing concern, with World resources depleting and demand increasing; it is expected that by 2035 fuel demand has increased 40% (IEA, 2012). Besides fuel scarcity, global CO_2 emissions resulting from fuel combustion pose serious threats through climate change. Current estimations predict CO_2 emissions to keep rising, even if abatement strategies are incorporated in the models. The two main contributors to CO_2 emissions are the electricity and heat sector and the transport sector, responsible for respectively 41% and 22.3% of global CO_2 emissions. Of the latter, 73.6% is caused by road transport (IEA, 2012). Even when major mitigation policies are included, predictions still estimate an increase of 40% in transport CO_2 emissions between 2007 and 2030 (ITF, 2010). To the emission of other greenhouse gas (GHG) emissions transport contributes 'only' 15% (ITF, 2010). Thus, the transport sector is of major interest for climate change mitigation strategies.

Climate change has severe impacts on livability, with expected impacts including, among others, warmer and more frequent hot days, rising sea levels, a higher frequency of heat spells and a higher frequency of heavy precipitation, but also more areas being affected by drought (UN-Habitat, 2011). This is especially troublesome for developing countries, as many of their cities are located in areas prone to flooding, droughts or on the coast, while the majority of CO_2 emissions originate from developed, rich countries. Furthermore, high incomes are deemed to have greater adaptive capabilities to changes imposed by climate change (UN-Habitat, 2011).

Meanwhile, today's world is urbanizing rapidly; in 2010 for the first time over half of the World's population resided in urban areas. This figure is expected to rise to 70% by the middle of this century (UN-Habitat, 2012). Especially emerging economies (EEs) and non-OECD countries in Latin America, Asia and Africa face large numbers of people moving to cities in the hope of finding income opportunities. Of these, Latin America is most urbanized, with 80% of the population living in urban areas, which is expected to increase to 87% by 2050 (UN-Habitat, 2012). This causes many social issues, since many people migrating to cities are forced to reside in slums in the outskirts of large metropolises, due to a lack of institutional provisions of housing security. These inhabitants lack sufficient access to (among others) water, education, healthcare, employment and transport opportunities. Consequently, social exclusion may occur. This results in income inequalities, which as a trend are still rising in OECD countries, with the Gini-index increasing from 0.29 in the mid-1980s to 0.32 in the late 2000s (OECD, 2011a). In emerging economies these income inequalities are significantly higher, which is mainly due to the informal sector, a lack of access to proper education and barriers for women. These inequalities mainly manifest in urban areas (OECD, 2011b).

Prosperity analyses show that to improve prosperity these inequities require more attention in urban decision making (UN-Habitat, 2012). Besides the aforementioned environmental sustainability and social inclusion, productivity, infrastructure and quality of life are other determinants of a city's prosperity. A study by UN-Habitat (2012) shows that in Latin American cities the focus should mainly be on productivity, generating local jobs, improving transport infrastructure, improving living conditions and reducing inequalities, while simultaneously protecting the environment. Cities can utilize their full productivity potential if barriers are decreased. This is mainly achieved by reducing traffic congestion, enhancing mass transit and providing efficient and reliable transport services (UN-Habitat, 2012).

3.1.2 SUSTAINABLE TRANSPORT

Besides urbanization issues, motorization is causing congestion problems in ever-expanding cities. Motorization in Latin America is highest for the developing world, at 169 cars owned per 1000 inhabitants in 2008, a figure which is expected to continue to increase (UN-Habitat, 2012). However, motorization trends in developing countries differ significantly from developed countries. Sperling and Claussen (2002) note that especially two-wheeler' numbers are increasing rapidly. This is particularly evident in Asia, but is also spreading to Latin America and Africa. These two-wheelers provide a cheap and affordable alternative to a car, because they are better navigable on crowded streets and cost only a fraction in purchase price. This private vehicle ownership is further stimulated due to competition within the public transport market, with various types of public transport competing over customers, instead of competing with private modes (Ardila, 2012).

Banister (2008) notes that this increase in vehicle ownership undermines sustainable transport and that transport is most sustainable in cities with a population over 50,000 inhabitants, with medium densities, mixed land use and public transport. However, Banister (2008) also highlights that over the years travel time has remained the same, but that speed and distance have increased, along with car dependence. This severely impacts the poorer segments of the population, who are excluded from some transport options. As a result, they experience fewer and longer trips, make more of them on foot or by other slow modes, have a higher vulnerability from traffic accidents and a limited number of services accessible (World Bank, 2002). Hence, a shift is required from conventional transport planning to sustainable transport planning. Such a change involves focusing on accessibility instead of mobility, a people focus instead of traffic focus and from economic evaluation towards multi criteria analysis also including social and environmental impacts (Banister, 2008). To promote such sustainable transport planning, Leather (2009) proposes the avoid-shift-improve approach. The avoid approach regards the avoidance of travel by limiting the need to travel. The shift approach concerns shifting travel to the most sustainable transportation mode. The improve approach aims at reducing emissions through technological advancement. Many public transport policies intend to induce a shift from private modes (taxi, car, motorcycle) to public modes.

In order to effectively implement transport policies, HM Treasury (2003) has developed a policy cycle for transport planning (see Figure 3-1). This policy cycle consists of six steps: the rationale, formulation of objectives, appraisal, monitoring, evaluation and feedback. The last two steps take place after the implementation phase. HM Treasury (2003) notes that for large or on-going projects an ex-post evaluation is most important. This information can provide important feedback for future project development, a wider policy debate and improvement of ex-ante appraisals. However, Berveling et al. (2009) note that policy makers often only focus on ex-ante appraisal and do not conduct an ex-post evaluation. This means that important information that can be obtained from ex-post evaluation is not acquired.

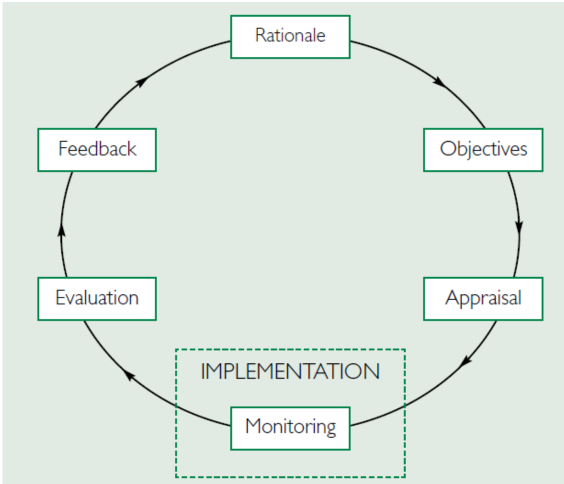

Figure 3-1: Policy cycle (HM Treasury, 2003).

3.1.3 PUBLIC TRANSPORT IN DEVELOPING COUNTRIES

Developing countries only have limited government regulation regarding public transport, despite the relevance of public transport for economic growth, poverty alleviation, safety and air pollution reduction. Often, governments do not impose entry barriers on the transport market, which results in many privately-owned vehicles offering transport services. These are often small vehicles such as minivans because they are easier to navigate (Ardila, 2012). However, this results in unsafe services, old and polluting vehicles, overcrowding and competition for customers. Nonetheless, use is high, because of the high frequency and coverage they offer, essentially providing door-to-door transport (Cervero and Golub, 2007).

This informal transport poses several problems, because an oversupply can cause inflated fares (Ardila, 2012). As a result, public transport often constitutes a large part of daily expenditure of users (Coorporación Andina de Fomento, 2009). Also, if more-organized, high-capacity transit systems are proposed, these existing bus operators often fear for their jobs and oppose all plans. Hence, it is necessary to involve existing bus operators in the planning process and restructure the public transport organization in such a way that existing bus operators can complement rather than compete with new public transport systems (Hidalgo and Carrigan, 2010). However, Sperling and Claussen (2002) indicate that in developing countries a lack of political commitment and public resources often limit the possibilities to tackle this problem. This makes it difficult to achieve radical changes to improve the efficiency of the public transport system. Nonetheless, some mass transit solutions have been successfully implemented in developing countries (Wright and Hook, 2007).

Mass transit systems have typically been implemented in the form of Mass Rapid Transit systems. MRT has been a popular way to provide high capacity urban public transit in many European, North American and Asian cities. However, high capital investments make such transport options unaffordable for many developing countries. In order to provide citizens with rapid transit operations without spending large sums of money, Curitiba (Brazil) introduced the Bus Rapid Transit system in 1974 (Wright and Hook, 2007). Since the implementation of Bogotá's TransMilenio BRT system in 2000, many other cities have followed suit, regarding BRT as a viable alternative to MRT and Light Rail Transit (LRT) systems. The World Bank has recommended BRT as appropriate infrastructure for developing countries due to significant impacts on externalities and successful implementation in many contexts (Timilsina and Dulal, 2011). Wright and Hook (2007) have published a BRT planning guide, defining BRT as a high-quality bus-based transit system that delivers fast, comfortable and cost-effective urban mobility through the provision of segregated right-of-way infrastructure with rapid and frequent operations. BRT capacities can, if implemented correctly, rival capacities of MRT systems, with capital investments ten to one hundred times lower (Wright and Hook, 2007). Meanwhile, BRT construction times are significantly shorter, providing short-term solutions to congestion problems as well as more flexible infrastructure to accommodate changing travel patterns (Deng and Nelson, 2013). Despite BRT's recent success, especially in Latin America, it is often still considered a second-hand alternative to rail options, such as LRT and MRT (Hidalgo and Gutiérrez, 2013). Hidalgo and Gutiérrez (2013) highlight that this is often caused by car users' perception of BRT taking up scarce space and claim that road capacity is reduced.

Public transport is often regarded as a transport mode for the poor. As a result, the affordability of public transport is often a point of discussion. Serebrisky et al. (2009) study the issue of affordability and public transport subsidies. Such subsidies often have two purposes: increase the use of public transport and improve the affordability, especially for the poor. Several types of subsidies exist, such as concessionary fares (free or discounted fares for certain groups), a flat fare structure (subsidizing longer journeys), infrastructure grants (government pays for construction costs of infrastructure) and quality self-selection (low incomes use lower quality and cheaper public transport and high incomes higher quality and more expensive public transport). However, Serebrisky et al. (2009) note that often transport subsidies are regressive and that focusing on inferior or necessity goods would be more effective. Often, this is because accessibility problems limit the effectiveness of transport subsidies.

3.2 COST-BENEFIT ANALYSIS

For some time, cost-benefit analysis has been a popular method to appraise the impacts of transport projects. Cost-benefit analysis is an ex-ante appraisal methodology applied regularly for transport project appraisal and is used frequently in the decision making process. CBA focuses on expressing a project's effects in monetary terms, so all effects are expressed in the same dimension. This way, effects can easily be summed and compared. Odgaard et al. (2005) provide an overview of the use of CBAs in project appraisal in Europe. This report shows that great differences exist between EU members. The Netherlands, for example, have a thorough framework for CBAs, while many EU members in Eastern Europe mainly apply CBAs because this is a requirement for EU funding. This section briefly discusses the CBA methodology, which is followed by an account of the major problems associated with CBA practice.

3.2.1 METHODOLOGY

The Dutch approach to (social) cost-benefit analyses is among the most comprehensive transport appraisal methodologies (Odgaard et al., 2005) and will therefore function as a guide for this overview. A CBA consists of several basic principles. First of all, several project alternatives are compared to a reference situation in which the project is not implemented (this is not a do-nothing scenario). This comparison is based on direct and indirect effects the transport project. The effects that are used in CBA (and other evaluation methodologies) are elaborated on in section 3.4. These effects are classified as costs (e.g. construction costs) and benefits (e.g. travel time savings) and can cover a broad scope (which is why sometimes the term social cost-benefit analysis is used). An important part of CBA is to prevent that effects are counted twice and thereby overrepresented in the outcome. What makes CBA specific is that all effects are quantified and monetized. The latter is often done using a shadow pricing methodology, such as the value of time. This way, all costs and benefits can be summed giving a single net present value (NPV) of each project alternative. Other evaluation criteria also exist, which are discussed in section 3.5. Often, CBA is a mandatory element in the decision making process (Eijgenraam et al., 2000).

The steps required to conduct a CBA are identified by Eijgenraam et al. (2000):

I. *Problem analysis*: this step focuses on the formulation of the problem and setting project goals, as well as the constraints imposed on the project (e.g. environmental targets);
II. *Project definition:* this step focuses on constructing several project alternatives, including a null alternative or reference scenario (no project developed);
III. *Identification of project effects*; the effects of the various project alternatives are identified (e.g. direct, indirect and external effects);
IV. *Estimation of relevant exogenous effects*; this step estimates the effects of the project surroundings on the project alternatives (e.g. national or global economic developments);
V. *Estimation and valuation of project effects*; the project effects identified in step III are estimated in this step (e.g. amount of travel time saved due to project);
VI. *Estimation of investment and exploitation costs*; all costs associated with the construction of the project alternatives are estimated;
VII. *Compose the cost-benefit overview*; in this step the previously estimated costs and benefits are compared to show the economic and social effects of the project alternatives (e.g. the net present value);
VIII. *Alternatives and risk analysis*; due to the risks and uncertainties associated with ex-ante analyses, in many of the previous steps these risks should be incorporated;
IX. *Additional tasks*; although the CBA is complete after the previous steps, additional tasks can include links to Public Private Partnerships and ex-post project evaluations.

Ramirez Soberanis (2010) also describes the steps used for CBAs in the Mexican transport sector, where CBAs are a legal obligation to access public funds. The first step is to identify the problem (Dutch step I). Then a ‘no project scenario’ scenario has to be developed, including some basic measures to optimize its situation (comparable to the null alternative in step II and exogenous effects in step IV). The project alternative(s) is defined (step II) and the project costs and benefits are quantified (step III, V and VI). Next, these costs and benefits are compared to the ‘no project scenario’ to calculate the benefits and costs in relation to the null alternative (step VII). These net costs and benefits are expressed in profitability indicators (such as net present value; step VII). Finally, a sensitivity and risk analysis are performed (step VIII) (Ramirez Soberanis, 2010). Thus, the Mexican approach is very comparable to the Dutch approach in terms of the properties of the analysis. However, this does not necessarily mean that the analyses are of comparable quality, because the accuracy and comprehensiveness of the analysis can still differ significantly. Furthermore, Mexican ex-ante appraisal is often applied when a project has already been selected. Hence, only the project situation and the null alternative are compared, and other project alternatives are not considered.

3.2.2 PROBLEMS

Despite CBA’s popularity, some methodological problems persist, as well as some problems that are more related to CBA in the decision making process. This paragraph discusses these issues, but only focuses on those related to CBA methodology. Some literature distinctly focuses on the issues associated with CBA, which forms the basis for the following discussion. The most important encountered problems are addressed subsequently.

One of the major CBA concerns is that not all effects are easy or even possible to monetize. This especially holds for social and environmental effects (Beukers et al., 2011; Mouter, 2012; Mouter et al., 2013; Thomopoulos and Grant-Muller, 2013; Wee, 2012). Sometimes shadow price methodologies are applied to monetize these impacts, but these impose great uncertainties in the estimation. However, even the estimation of non-monetized project effects is regarded extremely difficult for some impacts (Mouter et al., 2013), so the problem is even twofold for some effects. For example, impacts on natural heritage are difficult to quantify and to monetize, so often not (properly) represented in CBA. Especially transport projects aiming at less tangible goals, including public transport projects, are prone to this problem (Mouter, 2012). Hence, the question remains if and how effects are to be quantified and monetized.

A solution can be to leave some qualitative indicators in the CBA, such as improvement or deterioration of the natural environment. However, this poses some other problems. Firstly, these qualitative effects are not part of the CBA balance, so are easily ignored when the CBA is only studied briefly (Beukers et al., 2011). Mouter (2012) underscores this by stating that there is too much focus on the balance and less or no focus on the contents of the CBA report. Alternatively, ITF (2011) argues that it is better to include difficult quantifiable effects along with accuracy and confidence levels than to exclude them from the analysis. In Mexico only objective and easily monetized effects are included in CBA, excluding effects such as comfort and safety (Ramirez Soberanis, 2010). Hence, simply using qualitative indicators is not a straightforward solution.

Another major shortcoming of CBA is that distributive effects are not taken into account (ITF, 2011; Martens, 2011; Mouter, 2012; Mouter et al., 2012; Wee, 2012). Given the utilitarian approach of CBA, a project can be exceptionally beneficial for one person and slightly unbeneficial for one hundred people and still score positively (Mouter, 2012). In reality, decision makers are also interested in equity, which concerns the fairness of the distribution of effects. This concerns what is an ethically justifiable distribution, i.e. how much are some allowed to 'suffer' for the benefit of others. Moreover, this suffering may be more acceptable among some population groups (e.g. high income groups) than others (e.g. public transport captives) (Martens, 2011). This problem is exacerbated by the use of willingness to pay (WTP) in CBA, which is higher for high incomes (e.g. higher value of time) making their influence on CBA outcomes larger (Wee, 2011). Since these equity considerations are of major importance for an evaluation framework, some equity principles and options to limit the aforementioned equity issues are discussed in more depth in section 3.5.1.

3.3 EX-POST EVALUATION

Ex-ante appraisal is becoming increasingly popular, especially as a way to estimate effects beforehand and use this information as a decision making framework. Meanwhile, little attention has been paid to determining whether these effects have in fact been achieved and if projects have indeed been economically beneficial. This is especially relevant since many ex-ante appraisals are based on unrealistic assumptions, which results in an optimism bias, especially because decision makers often have a preferred policy option (Knudsen and Rich, 2013). Preston and Wall (2008) concur with this, claiming that benefits are often overstated, while costs are underestimated to ensure projects go ahead. Ex-post evaluations give evidence of the effectiveness of investments in terms of social, economic and environmental objectives. This evidence can be used to optimize the assumptions made in ex-ante appraisal (EVA-TREN, 2008).

Despite ex-post evaluation's lack of popularity, there is some literature on the subject, which mostly focuses on project costs (Annema et al., 2012). In the UK, Post Opening Project Evaluation (POPE) was introduced in 2001 to evaluate the impacts of major road schemes (Oxera, 2005).

Also in France transport projects are evaluated after opening, with a focus on social economic performance (Chapulut et al., 2005). In Norway annually approximately five road construction projects are selected for ex-post evaluation (Kjerkreit et al., 2008). Also in Mexico ex-post evaluation is officially part of the project development practice (Ramirez Soberanis, 2010). Hence, there is some literature available on ex-post evaluation, which is discussed below.

3.3.1 METHODOLOGY

In essence ex-post evaluation is similar to ex-ante appraisal. However, the main difference is that ex-ante appraisal focuses on looking forward, while ex-post evaluation is based on historic observations. Hence, the techniques used are comparable, so an ex-post evaluation can be regarded as a CBA which is not based on predictions but on what actually occurred (EVA-TREN, 2008). In fact, often an ex-post evaluation is based on an ex-ante appraisal and the same unit values are used for the monetization (Chapulut et al., 2005). However, current ex-post practice does not always include all indicators that are used in ex-ante appraisal (Berveling et al., 2009). For example, Oxera (2005) mentions the POPE program is limited to traffic volumes, travel times and accidents.

The steps described in section 3.2.1 are therefore also applicable to ex-post evaluations. The main difference is that CBA estimates a reference scenario, while ex-post evaluation estimates a scenario that is based on what the current situation would have been if the project was not implemented, called the counterfactual situation. In essence this is the same as in CBA, but estimations can be more precise, because comparable areas with no project influence can be used to approximate the counterfactual situation (EVA-TREN, 2008). Berveling et al. (2009) note that the decreased uncertainties obliterate the need to use scenarios, making a counterfactual situation easier than in ex-ante appraisal. Finally, the counterfactual situation is not based on a 'do-nothing situation', but portrays the most probable situation if the project would not have been implemented, so this does include, for example, maintenance (Chapulut et al., 2005).

Ex-post evaluation mainly differs from CBA in the way the effects are estimated. CBA is based on estimations, while ex-post evaluation can use actual data for estimation. Nonetheless, many different approaches are used. Preston and Wall (2008) estimate effects of high-speed trains in South East England using regression techniques to compare changes with surrounding regions. Knudsen and Rich (2013) use transport demand and transport costs before and after construction to estimate transport impacts. These effects are then extrapolated to approximate impacts for a longer time span, ignoring second and third order effects.

Annema et al. (2012) propose a quantitative analysis based on available monitoring data, complemented by surveys among users and local residents. Gospodini (2005) proposes using surveys in four different areas (radius of 500-1000 meters); areas around a central station, a peripheral station and a presumably unaffected station in the project corridor and a station away from the project corridor. The former two are the main survey areas and the latter two the control survey areas.

EVA-TREN (2008) suggests in-depth interviewing stakeholders and relevant professionals for supplementary qualitative research. Also in France interviews with approximately thirty political, economic or association executives are used to complete the quantitative approach (Chapulut et al., 2005). Using interviews could potentially eliminate the necessity of constructing a counterfactual situation, as experts can (qualitatively) estimate the effects (Oxera, 2005).

Hence, the three main methodologies consist of using quantitative data, surveys and (expert) interviews. These methodologies can be combined, because the suitability greatly depends on the indicator investigated. For example, travel time savings are more easily estimated by quantitative data or surveys, while changes in real estate values can also be estimated using interviews. This means the appropriate methodology cannot be prescribed, but depends on the specific situation.

3.3.2 PROBLEMS

Ex-post evaluations have some inherent methodological problems. Berveling et al. (2009) identify three of these: causality, timing and evaluation scope. Causality is the major problem, which results from the question to which extent the effects are the result of a project. The main challenge is to identify which effects are endogenous and which effects are exogenous (Berveling et al., 2009). Annema et al. (2012) note that short-term evaluation is easier than long-term evaluation, because exogenous effects are minimal. In a later stage other transport projects may be realized or urban developments may influence traffic. Hence, short-term evaluation can restrict this problem. Berveling et al. (2009) propose two solutions. The first is to model the counterfactual situation based on recent knowledge. The second is more behavioral and focuses on passenger surveys in which current and previous travel behavior is analyzed, including motives for behavioral change.

The second problem is related to the previous issue, because the timing of evaluation can pose two problems. Evaluating too early means not all effects may yet be observable, while evaluating too late means the aforementioned causality problem worsens. An optimum of three years is suggested (Berveling et al., 2009), but other studies suggest one (Oxera, 2005) and five years (Chapulut et al., 2005; Kjerkreit et al., 2008; Oxera, 2005), indicating that no consensus exists on this issue and that the optimum may be case specific.

The evaluation scope relates to the level that projects are evaluated on; on an individual project level or on a program basis encompassing several related projects. For simultaneous projects it may prove difficult to evaluate individual projects, because effects are not easily attributable to a single project. Nonetheless, it is recommended to evaluate on an individual project basis, because otherwise good and bad projects level each other out and the individual qualities of projects are disregarded (Berveling et al., 2009).

3.4 INDICATORS

Ex-ante appraisal and ex-post evaluation methodologies include many indicators of the project effects. Literature on CBA, ex-post evaluation and other public transit evaluations has been studied to present an extensive list of possible indicators for this research. An overview of these indicators is shown in Table 3-1. This is an extensive list of indicators, and as the references show, not all indicators are used in every context. For example, Odgaard et al. (2005) show that the effects most often excluded are disruption from construction, benefits to goods traffic, user charges and revenues and climate change. Some of the studies only considered indicators that are missing in current practice, while others describe only indicators in the current practice. Hence, if indicators are not mentioned in a study this does not necessarily imply that this indicator is not regarded relevant. Below the indicators are discussed very briefly, since the indicators used in the framework are discussed elaborately in chapter five.

Indicator group	Indicator	References
Infrastructure costs	Construction costs	Annema et al. (2012); Eijgenraam et al. (2000); Gospodini (2005); Hidalgo et al. (2013); ICF (2009); Kjerkreit et al. (2008); Litman (2013); Nijland et al. (2010); Odgaard et al. (2005); PROPOLIS (2004); Ramirez Soberanis (2010); TRB (2002)
	System operating costs and maintenance	Eijgenraam et al. (2000); Hidalgo et al. (2013); Kjerkreit et al. (2008); Odgaard et al. (2005); Ramirez Soberanis (2010); TRB (2002)
User benefits	Benefits to goods traffic	Odgaard et al. (2005)
	Comfort	Bakker and Zwaneveld (2009)
	Consumer savings	Litman (2007)
	Crowding	Bakker and Zwaneveld (2009); Li and Hensher (2011); Wardman and Whelan (2011)
	Distributional effects and equity	Bakker and Zwaneveld (2009); ICF (2009); Litman (2013); Oxera (2005); PROPOLIS (2004); Sammar et al. (2003); TRB (2002); Van Wee and Geurs (2011)
	Social exclusion	Oxera (2005); PROPOLIS (2004); Van Wee and Geurs (2011)
	Transport diversity/option value	Bakker and Zwaneveld (2009); Litman (2007, 2013); Oxera (2005); TRB (2002)
	Travel time savings	Annema et al. (2012); Eijgenraam et al. (2000); Hidalgo et al. (2013); ICF (2009); Kjerkreit et al. (2008); Litman (2013); Odgaard et al. (2005); Oxera (2005); PROPOLIS (2004); Ramirez Soberanis (2010); Sammar et al. (2003); TRB (2002)
	Vehicle operating costs	ICF (2009); Kjerkreit et al. (2008); Litman (2013); Nijland et al. (2010); Odgaard et al. (2005); PROPOLIS (2004); Ramirez Soberanis (2010); TRB (2002)
Externalities	Air pollution	Bakker and Zwaneveld (2009); Eijgenraam et al. (2000); Hidalgo et al. (2013); ICF (2009); Kjerkreit et al. (2008); Litman (2007, 2013); Nijland et al. (2010); Odgaard et al. (2005); Oxera (2005); PROPOLIS (2004); Ramirez Soberanis (2010); Sammar et al. (2003); TRB (2002)
	Climate change	Bakker and Zwaneveld (2009); Eijgenraam et al. (2000); ICF (2009); Litman (2007, 2013); Nijland et al. (2010); Odgaard et al. (2005); Oxera (2005); PROPOLIS (2004); Sammar et al. (2003)
	Congestion reduction/reliability	Eijgenraam et al. (2000); Litman (2007, 2013); Odgaard et al. (2005); Oxera (2005); TRB (2002)
	Noise	Bakker and Zwaneveld (2009); Eijgenraam et al. (2000); ICF (2009); Kjerkreit et al. (2008); Nijland et al. (2010); Odgaard et al. (2005); Oxera (2005); PROPOLIS (2004); Sammar et al. (2003); TRB (2002)
	Public health	Hidalgo et al. (2013); Litman (2007, 2013); PROPOLIS (2004)
	Safety	Annema et al. (2012); Bakker and Zwaneveld (2009); Eijgenraam et al. (2000); Hidalgo et al. (2013); ICF (2009); Kjerkreit et al. (2008); Litman (2007); Nijland et al. (2010); Odgaard et al. (2005); Oxera (2005); PROPOLIS (2004); Sammar et al. (2003); TRB (2002)
	Visual hindrance	Eijgenraam et al. (2000); Kjerkreit et al. (2008); PROPOLIS (2004)
Indirect effects	Avoided parking facilities	Bakker and Zwaneveld (2009); Litman (2013)
	Land value increase/TOD	Bakker and Zwaneveld (2009); Gospodini (2005); Litman (2007, 2013); TRB (2002)
Other indicators	Disruption from construction	Hidalgo et al. (2013); Litman (2013); Odgaard et al. (2005); Ramirez Soberanis (2010)
	Employment	Eijgenraam et al. (2000); Gospodini (2005); ICF (2009); Odgaard et al. (2005); Sammar et al. (2003); TRB (2002)
	Indirect economic effects	Bakker and Zwaneveld (2009); ICF (2009); Oxera (2005); Preston and Wall (2008); PROPOLIS (2004); Sammar et al. (2003); TRB (2002)
	Livability	Annema et al. (2012); ICF (2009); Kjerkreit et al. (2008); Oxera (2005); PROPOLIS (2004); Sammar et al. (2003)
	Lost tax revenues	Bakker and Zwaneveld (2009)
	User charges and revenues	Odgaard et al. (2005); TRB (2002)

Table 3-1: Possible indicators for the ex-post evaluation, based on literature.

The infrastructure costs consist of the construction costs and operating and maintenance costs. Construction costs include materials, labor, energy, land purchase, planning costs and mitigation. Some countries also include residual value, dependent on the appraisal period, often using straight line depreciation. System operating costs and maintenance include all costs associated with the operation, maintenance and renewal of infrastructure (Odgaard et al., 2005).

Many user benefit indicators are mentioned in literature. Benefits to goods traffic consist of vehicle operating costs, driver and crew wages and sometimes the costs of goods while in transit (Odgaard et al., 2005). Comfort during a trip directly affects travelers, but this effect is often not included in public transport CBAs due to difficulties expressing this in monetary terms. Comfort can include the type of vehicle (bus vs. train), more comfortable seats or air-conditioning (Bakker and Zwaneveld, 2009). Consumer savings relates to the money consumers spend on transport. If people switch from car to public transport, additional costs include ticket prices, but savings include fixed car costs (Litman, 2007). Crowding is caused by insufficient available seats which forces passengers to stand. World Bank (2002) notes that as a result, congestion tends to disadvantage passengers of crowded public transport more than travelers using their private car. Although most studies only include in-vehicle crowding, Li and Hensher (2011) indicate that access-way, entrance and station crowding also exists. Wardman and Whelan (2011) find that standing is experienced twice as burdensome as sitting. Wee and Geurs (2011) highlight that distributional and equity impacts are often left out of CBA, but that this can be of major importance for decision makers. Social exclusion relates to the lack of options to participate in a minimum of activities due to income- or transport-related barriers (Wee and Geurs, 2011). The option value of public transport addresses the value people associate with having the option to use public transport in case of emergency, for example when their car breaks down (Bakker and Zwaneveld, 2009). Travel time savings is the most important indicator in absolute terms and includes all changes in travel time from origin to destination, including access, egress, transfer and in-vehicle time (Odgaard et al., 2005). Since work trips have a significantly higher travel time value, these amount to half the travel time benefits, while only representing one sixth of total traffic (Mackie, 2010). Vehicle operating costs mainly consist of repair, maintenance, vehicle depreciation, fuel and material costs (Odgaard et al., 2005).

Externalities concern those effects that are not directly experienced by travelers, but that is imposed on their environment due to the trips they make. Air pollution concerns all vehicle emissions that affect the local air quality and pose health threats to people exposed to them. Some of these harmful emissions are carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), lead, hydrocarbons (HC) and particulate matter (Sammar et al., 2003). Climate change results from the emissions of GHGs. Often, only CO_2 is included in project appraisal, but sometimes ozone (O_3) and methane (CH_4) are also included (Odgaard et al., 2005). Besides user travel time savings, a transport project can also indirectly impact travel times of other travelers through reduced congestion resulting from a modal shift from car to public transit (Odgaard et al., 2005). Transport infrastructure construction and operation both produce noise that hinders nearby residents, which can be expressed in noise annoyance or health-related costs (Odgaard et al., 2005). Physical activity resulting from non-motorized transport (NMT) can accrue to significant public health cost savings. For transit trips walking and bicycling are often access modes and thereby reduce public health costs (Litman, 2013). Traffic accidents impose serious societal costs in terms of material damage, medical treatment, emergency services and production losses. Therefore, safety is often considered an important indicator in CBAs (Odgaard et al., 2005). Visual hindrance and physical barriers are a concern for residents when new transport projects are implemented. For example, an overpass can diminish the view from a house or apartment (Eijgenraam et al., 2000).

Indirect benefits basically concern positive externalities. Reduced car use due to transit improvements means significant savings are acquired in terms of payment for parking and higher values of land uses (Litman, 2013). The proximity to public transit stations can increase land and property values (Munoz-Raskin, 2010). However, World Bank (2002) notes that residents only profit from property value increases if they own the land themselves, which is often not the case for the poor.

Some indicators that could not be categorized in one of the previous descriptions were categorized in a final group. Disruption from construction includes effects such as delay and increased risks of accidents resulting from limited road capacity and more heavy vehicles on the road (Odgaard et al., 2005). Employment benefits regard employment due to construction, direct employment for operation and maintenance and indirect employment due to demand increase for shops, restaurants etc. (Odgaard et al., 2005). Indirect economic effects concern benefits for the economy due to agglomeration benefits resulting from people's and business' preference to reside in each other's proximity, causing higher productivity (Bakker and Zwaneveld, 2009). Livability comprises the quality of life and community development of the residents near transport projects, which can improve due to improved station areas, for example (Oxera, 2005). A loss of tax revenues can result from a modal shift from car to transit (Bakker and Zwaneveld, 2009). Contrarily, ICF (2009) claims governments can collect additional taxes due to new developments. Finally, user charges and revenues relate to revenues from transport exploitation. For public transport these are the tickets passengers buy, while for infrastructure projects, these can be tolls that are levied on road users. It has to be noted that transit fares are often subsidized, which provides a cost to governments (TRB, 2002).

3.5 EVALUATION CRITERIA

This section discusses several criteria that are used to evaluate the impacts of transport projects. First of all, some equity principles are explained, including a discussion on how equity can be incorporated in transport evaluation. Secondly, the aggregation of monetary indicators is addressed, which gives insights in how monetary performance of projects is expressed. Finally, non-monetary indicator aggregation is elaborated on.

3.5.1 EQUITY THEORIES

Due to increasing inequalities, especially in developing countries, equity is becoming increasingly important in transport appraisal. Wee and Geurs (2011) define equity to be associated with fairness and justice and hence includes moral judgment. The term is not to be confused with equality which refers only to the distribution of a good or effects (e.g. income) without moral judgment. Hence, an equitable situation is not necessarily equal, nor vice versa.

Several equity principles or theories of justice exist. Both Thomopoulos and Grant-Muller (2013) and PROPOLIS (2004) propose six types. First of all, the utilitarian approach, used in CBA, maximizes utility for all impacted regions, regardless of the distribution. Secondly, the equal shares principle distributes all benefits equally. Thirdly, egalitarianism is based on the theory that all human beings are equal. The goal is to reduce existing inequalities by providing more benefits to less advantaged groups. Fourth, Rawl's theory of justice or the difference principle focuses on distributing project benefits to the most disadvantaged until they reach the level of the most advantaged. Wee and Geurs (2011) define these latter three theories as egalitarian theories. Fifth, average net benefits can be maximized with a minimum floor benefit, in which all affected groups or individuals are allocated a minimum level of benefits. Finally, average net benefits can be maximized with a benefit range. This approach maximizes the range of the distribution of project benefits, aiming to limit the widening of welfare differences. The latter two approaches are called sufficientarianism theories by Wee and Geurs (2011).

Shi and Zhou (2012) differentiate equity types in horizontal and vertical equity. The former concerns how impacts are distributed among individuals and groups with similar socio-economic characteristics. The latter involves impact distribution among individuals and groups that differ in socio-economic characteristics. Thomopoulos and Grant-Muller (2013) mention three additional equity types. Environmental equity benefits environmental protection, which is achieved through compensation or direct policies. Spatial equity involves how benefits are spatially distributed, often focusing on distributing benefits to disadvantaged and remote regions rather than central areas. Finally, the accessibility objective focuses on improving accessibility for all impacted regions.

Of the aforementioned equity principles, utilitarianism is used for CBA. However, several arguments can be made that this purely economic perspective does not incorporate equity issues sufficiently. Shi and Zhou (2012) highlight the principle of diminishing marginal utility, which states that if income increases the value of money decreases. Hence, fifty euros is worth more for a low-income household than for a high-income household. This implies public policies focusing on low-income groups are more efficient. Wee (2011) adds that the use of income-dependent values of time results in overrepresentation of high-income groups in CBA. Since high-income groups value their time higher than low-income groups, equal time savings represent a higher monetary value for high-incomes. Theoretically, this could mean the monetary value of one high-income person saving ten minutes of travel time equals that of one hundred low-income persons also saving ten minutes of travel time. Wee and Geurs (2011) also highlight that low incomes have a low WTP for new public transport services which may make it difficult to evaluate social exclusion reduction options.

Several ways to better incorporate equity issues in transport project evaluation exist. In order to overcome value of time issues, an equity value of time, based on the average income level, can be used. This way, travel time savings are valued equally for low- and high-income groups (Martens, 2011; Wee, 2011). Martens (2011) proposes using distributional weights, in which decision makers can attach different weights to gains for different groups. For example, higher weights can be attached to particular population groups based on political preference. Martens (2011) also suggests that a separate equity analysis can be conducted in addition to standard (CBA) transport appraisal. This way, distributive effects become clearer. The division into groups for this analysis may depend on the equity objective; for net benefits income groups are useful, while for mobility-enhancing benefits car ownership is also appropriate. For some single benefits or costs other relevant criteria are possible (e.g. spatial distribution for air pollution or men vs. women). If transport projects result in undesirable distributive effects, governments can compensate these disadvantaged groups (Shi and Zhou, 2012). This can be accomplished by measures such as taxes (Martens, 2011).

3.5.2 MONETARY AGGREGATION

Indicator aggregation can be completed in several ways. CBA and many ex-post evaluations express all effects in monetary terms and aggregate these. Several parameters are of importance for the results of an ex-ante appraisal (e.g. step VII of a CBA) or ex-post evaluation. These include discount rates, risk assessment, the appraisal period and the criteria used for comparison. These parameters are discussed in turn.

The discount rate is important to express the value of money that is earned or spent in the future in terms of the current value of money. Due to inflation, the value of money generally decreases over time; one Euro is worth more now than it will be in ten years. Also, if money is not spent it can be invested on the stock market. The discount rate differs greatly between countries, and should be determined based on the rate of return if money is otherwise invested on the international capital market (Eijgenraam et al., 2000). The discount rate used in the Netherlands is 4%, but Germany uses a rate of 3% and France uses a rate of 8% (Odgaard et al., 2005). In Mexico a social discount rate of 12% is used (Ramirez Soberanis, 2010). Risk assessments are often excluded from CBA, mainly because risk estimation is extremely difficult in practice (Odgaard et al., 2005). Eijgenraam et al. (2000) suggest adding a risk premium to the discount rate, realistically around 6%. This way future risks can be incorporated in the analysis.

The appraisal period is important for CBAs because this indicates the period over which benefits and costs are estimated. The main (construction) costs for a public transit project are made in the implementation phase, while many of the benefits are enjoyed during the operation phase over a prolonged period of time. This means the appraisal period is extremely important for the results of a CBA. In theory, the appraisal period would encompass the entire lifespan of a project. However, in practice it is uncertain when the impacts of a transport project end, because infrastructure measures can have long-lasting effects on urban planning. Furthermore, due to discount rates being used, the net benefits decrease annually. The time horizon in the Netherlands is not explicitly specified, but an appraisal period of maximum twenty to thirty years is recommended. After that period benefits are too uncertain, so these are disregarded. However, the residual value of the infrastructure can function as an estimation of all benefits after the appraisal period (Eijgenraam et al., 2000). Appraisal periods in Europe range from twenty years (e.g. Portugal) to fifty years (e.g. Denmark) (Odgaard et al., 2005). Ex-post evaluations are conducted one (Oxera, 2005), three (Berveling et al., 2009) or five years (Chapulut et al., 2005; Kjerkreit et al., 2008; Oxera, 2005) after implementation. The main reason to evaluate shortly after implementation is that the causality problem is minimized. However, in order to accurately include all the benefits of a project, these effects should be extrapolated for the same appraisal period as for CBA, because costs are made before implementation and benefits only enjoyed for the period thereafter. Overall, a suitable appraisal period will have to be decided based on the project.

There are several criteria that can be used to evaluate the costs and benefits of a project. The main criteria are the net present value, benefit/cost ratio (B/C ratio) and internal rate of return (IRR), while other criteria such as first year benefits and pay-back period are less frequently used (Odgaard et al., 2005). The NPV monetizes all effects and expresses these, using the discount rate, in the present value. A profitable project is characterized by a positive NPV (Eijgenraam et al., 2000). Evaluation using the B/C ratio uses the same methodology, but instead of calculating the balance, the benefits are divided by the costs. The resulting value gives an indication of how efficient investments are; a higher B/C ratio means the investments are more cost efficient. IRR uses the appraisal period, costs and benefits to determine the maximum discount rate at which the project is still profitable (Eijgenraam et al., 2000). This gives a good indication of the risks associated with project implementation. In Mexico, a minimum social IRR of 12% is required to access public funds (Ramirez Soberanis, 2010). The pay-back period determines the time at which the summed benefits exceed the costs, without using discount rates (Eijgenraam et al., 2000). Finally, the first year benefits give an indication if the timing of the project is appropriate, or that postponement is desirable (Eijgenraam et al., 2000).

3.5.3 NON-MONETARY AGGREGATION

Besides monetary aggregation, several non-monetary aggregation methods exist. Odgaard et al. (2005) mention multi-criteria analysis (MCA) as an aggregation method which uses unique weights per effect to gain an overall score. Sammar et al. (2003) note that sometimes key actors can be consulted to determine the weights, while also a set of experts within a company can be used to determine these weights. Alternatively, stakeholders can estimate weights and each stakeholder's contribution factor can then determine the weight the indicator requires. Also, this can provide insights in how performance differs over different stakeholders (Thomopoulos and Grant-Muller, 2013). ITF (2011) regards this a potential weakness, as this can result in subjectivity. Scenarios with different weights can be used to illustrate the differences in preference. Medda and Nijkamp (2003) use combinatorial assessment to combine different assessment methods, such as regime analysis and flag model combinations.

PROPOLIS (2004) uses a similar approach, but group indicators in the three dimensions of sustainability: the environmental, social and economic dimension. For each dimension a final score is determined, allowing judgment of the performance of a policy option on all three dimensions. This way, it can be easily seen if a project scores well on economic and social indicators, but poor on environment, for example. This makes it easier for policy makers to select a policy option that best suits their priorities. All three dimensions consist of a multitude of indicators, which are aggregated using weights based on expert consultation. Some indicators occur in several dimensions (e.g. air pollution), so aggregating the three dimensions is not an option because this results in counting same effects twice. Sammar et al. (2003) also groups indicators into economic, social and environmental objectives, but attributes a weight of one third to each, so a final score can still be determined.

Nijkamp and Ouwersloot (1997) propose the flag model as an aggregation method for sustainability issues. The method consists of establishing critical threshold values (CTVs) for cost and benefit indicators. For cost indicators, the indicator is sustainable if the indicator is below a maximum CTV, while a benefit indicator is sustainable if the indicator is above a minimum CTV. However, due to uncertainties in CTVs, often a band width is added with a minimum and maximum CTV. In the case of a cost indicator, this means that below the minimum CTV the option is entirely sustainable ('green flag'), between the minimum and normal CTV the option is moderately sustainable ('orange flag'), between the normal and maximum CTV the option is moderately unsustainable ('red flag') and above the maximum CTV the option is unsustainable ('black flag'). This way each indicator is classified according to a flag, indicating the sustainability of the indicator. Aggregation can then occur by summation of each flag type per policy option. The total of each flag displays how sustainable the option is overall and allows for comparison between policy options. Medda and Nijkamp (2003) combine the flag model with a rough set analysis and the regime method to determine accepted, neutral and rejected policy options in a combinatorial assessment method. An overview of studies on, monetary and non-monetary, aggregation methods is shown in Table 3-2.

Reference	Objective	Data	Method	Outputs	Improvement
Eijgenraam et al. (2000)	Contribution of transport projects to welfare	Monetized effects	Monetary aggregation	NPV, IRR, payback time	-
Odgaard et al. (2005)	Contribution of transport projects to welfare	Monetized effects	Monetary aggregation	NPV, B/C ratio, IRR	-
Bakker and Zwaneveld (2009)	Estimate effectiveness of CBA in PT projects	Monetized and non-monetized effects	Monetary aggregation	-	Not all effects can be monetized or quantified, not well represented in CBA
Sammar et al. (2003)	Provide qualitative and quantitative evidence for impacts transport investment	Project effects (different dimensions)	MCA, using normalized weights based on experts. Effects divided by investment costs	Change in social utility (related to investment costs)	-
PROPOLIS (2004)	Develop and test land use and transport policies	Project effects (different dimensions)	Direct weighting method (weights per theme and indicator), fitted using min. and max. values	Change per theme and overall	-
Medda and Nijkamp (2003)	Transport policy options decision	Qualitative transport assessment	Rough set analysis (determine attribute weights), regime analysis (determine hierarchy), flag model (critical values, sustainability)	Accepted, neutral and rejected alternatives	-
Nijkamp and Ouwersloot (1997)	Construct comprehensive impact model with all sustainability variables	Measurable sustainability indicators	Flag model: using normative reference values to identify sustainability of scenarios	Sustainability of policy options	-
Joumard and Nicolas (2010)	Determine most sustainable transport project	Relative change per project effect	Weighted aggregation, with minimum values for (some) sustainability dimensions	Weighted score (per dimension)	Incorporate long-term effects
Paracchini et al. (2011)	Develop aggregation framework for ex-ante land use policy including trade-offs	Quantitative project effects (different dimensions)	Indicator normalization or scaling, weights based on expert consultation and trade-offs in evaluation space	Weighted score, overview of evaluation space and trade-offs within that space	-
Ex-post evaluation					
Thomopoulos and Grant-Muller (2013)	Incorporate wider impacts into appraisal than CBA does	Equity values	Analytic Hierarchy Process, different weights per stakeholder and different equity principles	Equity indicator results (no dimension), % change	CBA unable to address intangible social and environmental concerns, not possible to monetize
Oxera (2005)	Framework for ex-post evaluation in UK	Monetized effects	Monetary aggregation	NPV, IRR, B/C ratio	-

Table 3-2: Aggregation methods in various studies.

3.6 SURVEY DESIGN

This section discusses literature on survey design. First of all the steps for designing a survey are discussed. After that, some theory is explained about the calculation of an appropriate sample size.

3.6.1 SURVEY DESIGN PROCESS

The design of a survey is a complicated process consisting of many steps. Richardson et al. (1995) and Schaller (2005) provide a good overview of the survey design process. The first step of the survey design is the problem definition. A problem is the difference between the desired state of a system and the actual state of the system. However, a transport problem may never be solved, because solving a problem in one area may worsen the problem in another area (Richardson et al., 1995). In the second step, the system boundaries are set. The system's boundaries can be subdivided into social, spatial and temporal boundaries. Social boundaries concern the social groups included in the analysis (e.g. users and non-users), spatial boundaries concern the geographical boundaries of the analysis (e.g. corridor and network) and temporal boundaries relate to the time horizon which is considered (e.g. short-term and long-term) (Richardson et al., 1995). The third step involves the setting of objectives. This step focuses on the questions that should be answered by the survey. However, Richardson et al. (1995) note that for research study surveys it may be difficult to set clear objectives.

The next step is to review the existing information. The main goal of this step is to ascertain that the information that is gathered is in fact new information. If this is true, then hypotheses are formulated. This step is important to get an idea of what is to be measured and at what level of accuracy. A literature review can be used to formulate hypotheses. Next, some research terms are defined. These especially concern transport-related terms, which may be obvious to the survey designer, but may not be as unambiguous to other people involved in the conduction of the survey. It is important to do this, as the definition of these terms should be clear for respondents to gather significant data. This step is followed by defining the content of the survey. The survey content consists of a wish list of desired information necessary for the research, which consists of two parts. First of all, information is required for the estimation of the indicators. Secondly, information on weighting criteria is necessary for data expansion (Richardson et al., 1995).

After this, the most appropriate survey method is to be selected. Many different survey methods exist, ranging from household self-completion surveys to intercept surveys to in-depth surveys. These surveys mainly differ in complexity, the level of interaction between respondent and survey designer and types of information that can be collected (Richardson et al., 1995). Schaller (2005) notes that for public transport on-board and intercept surveys have higher response rates. Also, these surveys have the ability to target specific routes, obtain a representative sample and acquire more accurate, reliable and detailed information.

After the survey method is selected, the target population is defined. This comprises the entire population about which one would like to collect data. This population can be defined by households, persons, geographic areas or others (Richardson et al., 1995). Care has to be taken with implicit weighting. Neff and Pham (2007) highlight that if transit is used more often, there is a higher chance of being selected for the survey. Hence, the collected data describe the average transit rider and not the average person who rides transit. Schaller (2005) notes that the survey objective determines if the focus should be on riders or trips. The former is appropriate for researching customer characteristics, such as customer satisfaction and demographics. The latter is more appropriate if the goal is to acquire characteristics of trips, such as OD patterns and trip purposes. Another important part is the selection of respondents, because randomness is required to select a representative sample. If, for example, respondents are selected based on appearance (i.e. if they seem open to participate) the representativeness of the sample is impaired. In order to ensure randomness, every third or fifth person entering the station can be selected (Schaller, 2005). A final consideration for the study sample is the use of stratification. Stratified samples can be used in order to represent key subgroups in the sample. For example, stratification can take place for the time of day or boarding station.

3.6.2 SAMPLE SIZE

A survey sample size is not determined in a straightforward calculation, because many subjective inputs are required, which increase uncertainty. As a result, the sample size is often a trade-off between reliability and costs (Ortúzar and Willumsen, 1990). A very large sample size provides high reliability, but is expensive. A small sample size is more affordable, but provides limited reliability. Hence, a balance between the two has to be found. Richardson et al. (1995) indicate three factors that influence the required sample size: the variability, the degree of precision and the population size. Interestingly, the latter is least important, as the population size only significantly influences sample size for small populations. In order to determine the required sample size the standard error has to be determined, using Equation 3-1.

$$SE(m) = \sqrt{\frac{N-n}{N} \cdot \frac{\sigma^2}{n}}$$ **Equation 3-1**

Where:

SE(m)	Standard error of the mean *m*
N	Population size
n	Sample size
σ	Standard deviation

For large population sizes, the term *(N-n)/N* approaches one, which means the formula can be reduced to Equation 3-2.

$$SE(m) = \sqrt{\frac{\sigma^2}{n}} = \frac{\sigma}{\sqrt{n}}$$ **Equation 3-2**

This shows that quadrupling the sample size only halves the standard error. The previous two equations can be solved in two steps (Richardson et al., 1995). First Equation 3-3 is used, after which correction for the population can be applied, if a small population is studied, see Equation 3-4.

$$n' = \frac{\sigma^2}{\left(SE(m)\right)^2}$$ **Equation 3-3**

$$n = \frac{n'}{1 + (n'/N)}$$ **Equation 3-4**

Normally, the standard error is determined after a survey, based on observed patterns. However, this is not possible for determining the sample size. For this reason the standard error is often expressed assuming normal distribution. A level of confidence is selected and a corresponding unit normal distribution values (abbreviated to *z*) is used. For transport surveys a 95% confidence level is often assumed, with a corresponding value of *z* of 1.96, assuming a normal distribution. This means that there is a 95% probability that the error of the mean will not exceed 1.96 times the standard error. A second indicator is used, which is the confidence limit. A 10% error means that values may differ 0.1 times the mean. The new expression for the standard error is shown in Equation 3-5 (Richardson et al., 1995).

$$SE(\mu) = \frac{confidence\ limit}{z}$$ **Equation 3-5**

If the standard error is known, as well as the standard deviation, then the required sample size can be calculated.

3.7 CONCLUSIONS

A large amount of literature has been discussed in this chapter. Some of the main conclusions that are relevant for the research methodology are addressed here. Since the research objective is to develop an ex-post evaluation framework for BRT and MRT in Mexico, the main conclusions regard ex-post evaluation. The literature review shows that ex-post evaluation is not common in transport evaluation, but that this is certainly possible. However, it is difficult and time-consuming to accurately estimate effects. Therefore it is necessary to limit the number of indicators to several important indicators. These indicators should either be specifically relevant for Mexico or represent a large fraction of total impacts. The literature review shows that travel time savings often represent at least half of the economic benefits. Furthermore, inequality is an important issue in developing countries. However, equity has often been left out of CBA and ex-post evaluation, because this is difficult to monetize. Therefore, it may not be desirable to monetize all effects, but only those providing economic benefits. This also means that indicators do not necessarily have to be quantified, because some qualitative indicators can also provide insights in the impacts. This makes it easier to estimate effects, which can save time and therefore increase the number of indicators included. Another option to save time is to use values found in literature to estimate impacts, such as average emissions per vehicle kilometer travelled or the value per ton of emitted gas. Even though monetary aggregation is difficult, other aggregation methods, such as the flag model, are applicable.

CHAPTER 4. SUSTAINABILITY AND TRANSPORTATION IN MEXICO

This chapter discusses sustainability and transportation in Mexico in general, and in Mexico City in specific. First of all, some general information is given on Mexico. Secondly, social and environmental issues in Mexico City are discussed, as well as the organization of transport in the city. Furthermore, this section describes the political context of Mexico City. Third of all, the Metro system of Mexico City is elaborated on, with a special focus on line twelve which is evaluated in this study. Fourthly, the same is done for the Metrobús system, which also includes the history of the implementation of the Metrobús, as well as a focus on the fourth line, which is studied in this research. Finally, some conclusions on sustainability and transportation in Mexico (City) are given.

4.1 MEXICO

Mexico is becoming increasingly urbanized, with already 77.8% of the population of over 112 million people living in urban areas in 2010 (INEGI, 2010), which is expected to increase to 83.3% by 2030. This urbanization has caused several problems, because by 2007 14.4% of the urban population was residing in slums (UN-Habitat, 2012). Additionally, great income disparities exist, as the income deciles indicate. Table 4-1 shows the monthly household income per income decile for Mexico. The average monthly household income is 12,667 Mexican pesos (US$ 966). However, the highest income decile earns more than twenty-one times as much as the lowest income decile (INEGI, 2012). This ranks Mexico amongst the most unequal countries in the world (UN-Habitat, 2012). This is confirmed by Mexico's Gini-index of 0.453, which is a measure for income equality, with zero being perfectly equal (everyone same income) and one completely unequal (one person earns everything) (INEGI, 2012). Mexico's Gini coefficient is the highest of all OECD countries and is still increasing (OECD, 2011a). As a result, in 2012 45.5% of the Mexican population lived in poverty (53.3 million people), of which 21.5% lived in extreme poverty (11.5 million people). Another 33.9% of the population is vulnerable for poverty, either due to social inadequacies or income. Hence, only 19.9% of the Mexican population is not vulnerable for poverty (CONEVAL, 2012b). Other research indicates that 8.2% of the population has to live with less than US$2 per day and 4.0% even with less than US$1.25 per day (UN-Habitat, 2011). All these figures suggest great social and economic issues exist in Mexico.

Income decile	Household income (US$)
I	159
II	280
III	381
IV	481
V	591
VI	720
VII	893
VIII	1,139
IX	1,571
X	3,446
Average	**966**
Gini	**0.453**

Table 4-1: Monthly household income per income decile (INEGI, 2012).

Also environmental concerns are becoming increasingly important in Mexico. Mexico has committed herself to ambitious GHG abatement goals. Mexico has pledged to reduce GHG emissions by 30% by 2020, compared to the business-as-usual projection. Furthermore, Mexico aims to reduce GHG emissions by 50% by 2050, compared to 2000 emission levels (ITF, 2010). Mexico has also committed, along with eight other Latin American nations, to the Bogotá declaration, in which guidelines have been set for sustainable transport in the region (Foro de Transporte Sostenible de América Latina, 2011). Thus, Mexico certainly is taking some steps towards environmental sustainability.

Environmentally, especially the transport sector is of the utmost importance, since the sector is responsible for the largest part of CO_2 emissions (36.3%), while the largest global sector (electricity and heat) contributes only 29.6%. Of the transport CO_2 emissions, the vast majority is from road transport (97.3%) (IEA, 2012). These CO_2 emissions equal a total of 1.4 tons of CO_2 per capita (4.3 ton CO_2/capita in total), compared to 6.0 tons of CO_2 per capita in the USA, 2.1 tons of CO_2 per capita in the Netherlands and 0.0 tons of CO_2 per capita in India. However, Mexico's transport CO_2 emissions per GDP are comparable to the USA, emitting 0.13 kg CO_2/\$GDP and 0.16 kg CO_2/\$GDP respectively, and significantly higher than the Netherlands (0.07 kg CO_2/\$GDP) (ITF, 2010). Hence, if wealth increases in Mexico, it is expected that (per capita) emissions will increase as well.

However, a study of the externalities in Mexican road transport indicates that GHG emissions are not the main external costs, as these contribute to only 21% of all externalities. Accidents are the main contributor, which are responsible for 28% of all externalities, and also congestion imposes higher costs (22%). Other externalities are air pollution (13%), noise (9%) and infrastructure (7%). In total, these externalities amount to almost US$ 60 billion per year, or around 6.4% of Mexican GDP (Cravioto et al., 2013). These externalities can partially be explained by the large increase in the number of vehicles in Mexico, which increased from just under six million in 1980 to 15.6 million in 2000 and over 35 million in 2012, increasing car ownership to 0.311 (INEGI, 2013b).

4.2 MEXICO CITY

This section discusses sustainability and transportation in Mexico City. First of all, current sustainability indicators and characteristics of the city are given. Secondly, some policies that focus on sustainability or transport are discussed.

4.2.1 CITY CHARACTERISTICS

Mexico City is a name that is often used to describe a conglomeration of previously separate cities. Mexico City is best described as the Mexico City Metropolitan Area (MCMA) or its Spanish equivalent: Zona Metropolitana del Valle de México (ZMVM). In this report these three names are used interchangeably. The MCMA actually consists of several states and the Federal District (which, officially, is not a state). The Federal District is the center of the city providing residence to 8.9 million inhabitants (INEGI, 2010). Together with parts of the surrounding states Estado de México and Hidalgo this forms the MCMA. The total population of the MCMA accrues to 21.1 million inhabitants, 18% of the national population, of which 42% reside in de Federal District, 52% in Estado de México and the remaining 5% in Hidalgo. Hence, mainly the Federal District and Estado de México are considered in this study, as these comprise the majority of the MCMA population. The MCMA is the nation's economic center, producing 27.2% of the national GDP. The Federal District is the main location for employment, while the Estado de México is more residential. As a result, traffic flows are directed towards the Distrito Federal in the morning, while in the afternoon many employees return to the Estado de México (Ciudad de México, 2013b). For this study the Federal District is the most important part of the MCMA, because the Metro and Metrobús are both located within the confines of the Federal District. The Federal District consists of sixteen *delegaciones* or boroughs, see Table 4-2 for the names and population.

UN-Habitat (2012) studied the prosperity of Mexico City, along with a large number of other cities, using the City Prosperity Index (CPI), ranging from zero (least prosperous) to one (most prosperous). A city's CPI consists of five dimensions: productivity, infrastructure development, quality of life, equity and social inclusion and environmental sustainability. If four dimensions are used (excluding equity) Mexico City is categorized as a first category of solid prosperity factors (CPI: 0.816). However, if all five dimensions are included, Mexico City's CPI drops dramatically to 0.709. Hence, it is not surprising that Mexico City scores well on all indices except equity: productivity (0.743), quality of life (0.764), infrastructure (0.900), environment (0.866) and equity (0.405) (UN-Habitat, 2012). This suggests Mexico City performs relatively well economically and environmentally, but that especially many social issues are still prevalent.

These social issues manifest in poverty. CONEVAL (2012b) shows that poverty is more widespread in Estado de México (45.3%) than in the Federal District (28.5%). Extreme poverty is also more evident in Estado de México (5.8%) than in the Federal District (2.2%). This is further illustrated in Figure 4-1, which shows that the Federal District is among the states with the least poverty in the country, while Estado de México's poverty is around the national average. For the Federal District a further distinction is made per borough in Table 4-2. This shows that the boroughs with the most poverty are Milpa Alta, Tláhuac, Iztapalapa, Álvara Obregón and Gustavo A. Madero, which are mainly located in the (south)east. The boroughs with the least poverty are Benito Juárez, Miguel Hidalgo, Cuajimalpa de Morelos, Coyoacán and Azcapotzalco, which are mainly located in the center and west (CONEVAL, 2012a). The locations of these boroughs are shown in Figure A-1 and Figure A-2 in Appendix A.

Borough	Demographics			Trips[1]		
	Population[2]	Poverty[3]	Extreme poverty[3]	Production	Attraction	Internal
Azcapotzalco	414,711	20.6%	0.9%	646,293	649,253	217,618
Benito Juárez	385,439	8.7%	0.4%	982,823	986,277	258,559
Coyoacán	620,416	20.0%	1.3%	1,100,687	1,103,951	377,247
Cuajimalpa de Morelos	186,391	19.7%	1.6%	248,262	248,984	119,184
Cuauhtémoc	531,831	23.7%	1.4%	1,685,565	1,695,206	358,903
Gustavo A. Madero	1,185,772	30.7%	2.0%	1,449,508	1,453,531	661,145
Iztacalco	384,326	25.5%	1.4%	490,265	491,666	116,800
Iztapalapa	1,815,786	37.4%	3.2%	1,821,880	1,812,574	878,538
La Magdalena Contreras	239,086	30.3%	2.2%	234,456	234,041	94,440
Miguel Hidalgo	372,889	14.3%	0.5%	941,989	941,402	229,369
Milpa Alta	130,582	48.6%	6.2%	79,718	79,677	40,396
Tláhuac	360,265	26.8%	2.5%	278,465	277,306	106,674
Tlalpan	650,567	38.5%	3.4%	854,410	853,662	380,939
Venustiano Carranza	430,978	27.4%	1.8%	648,620	656,503	159,968
Xochimilco	415,007	28.4%	2.7%	394,415	394,491	191,054
Álvaro Obregón	727,034	31.3%	2.4%	954,818	954,641	405,635
Total	**8,851,080**	**28.7%**	**2.2%**	**12,812,174**	**12,833,615**	**4,596,471**

Table 4-2: Overview of population, poverty and number of trips per borough of the Federal District.

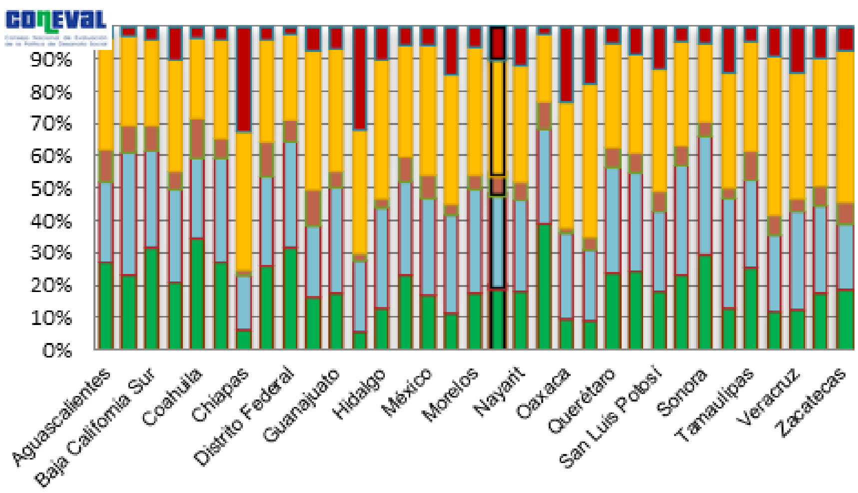

Figure 4-1: Poverty (yellow), extreme poverty (red), vulnerability for income (orange) and social deprivation (blue) and non-poor and non-vulnerability (green) per Mexican state (CONEVAL, 2012b).

Also in terms of income inequalities great disparities exist in Mexico City. Income inequalities are larger in Estado de México, which has a Gini-index of 0.436 in 2012, while the Federal District has a Gini-index of 0.413 (INEGI, 2012). The interpretation of the Gini-index is elaborated on in section 5.4.1.1. For both states the Gini-index is lower than the national

[1] Ciudad de México (2007)
[2] INEGI (2010)
[3] CONEVAL (2010)

average, indicating less income inequality in the MCMA. The Gini-index per borough of the Federal District is shown in Figure A-3 in Appendix B, indicating that the most unequal boroughs are Cuajimalpa de Morelos, Tlalpan, Coyoacán, Miguel Hidalgo and Benito Juárez. The most equal boroughs are Tláhuac, Milpa Alta, Iztapalapa, Gustavo A. Madero and Iztacalco (CONEVAL, 2012a). Interestingly, the most equal boroughs experience the most poverty, while the most unequal neighborhoods show least poverty. These income inequalities are also evident in the income deciles, with the highest income decile earning almost fifteen times as much as the lowest income decile in the Federal District and even almost nineteen times as much in the Estado de México, see Table 4-3. Nonetheless, this is still more equal than the national average.

Income decile	Federal District (US$)	Estado de México (US$)
I	295	191
II	467	331
III	586	442
IV	712	518
V	837	627
VI	997	753
VII	1,213	915
VIII	1,529	1,151
IX	2,099	1,501
X	4,303	3,567
Average	**1,304**	**998**
Gini	**0.413**	**0.436**

Table 4-3: Monthly household income per income decile for MCMA (INEGI, 2012).

A survey on employment in Mexico shows that a large part of the potential working population of Mexico City is economically inactive (around 40%). Of this economically inactive population the majority are students or people working in the household. Of the economically active population the vast majority is working as an employee (around two thirds). A significant part of almost a fifth is self-employed, while unemployment is relatively low around six percent. The population is reasonably educated, with the majority of the population having finished secondary education and a significant part of the population has achieved a higher level of education (INEGI, 2013a). This information is shown in more detail in Table 4-4 for the Federal District, Estado de México and the MCMA overall. The Federal District and Estado de México show comparable figures, although disparities exist in the level of education, which is generally higher in the Federal District.

		Federal District	Estado de México	MCMA
	Population >14 years	7,169,928	12,251,054	15,219,519
	Economically active	61.6%	58.7%	60.3%
Active	Employees	69.8%	66.5%	68.1%
	Employers	3.6%	3.0%	3.4%
	Self-employed	18.1%	20.0%	18.9%
	Unpaid work	2.6%	4.3%	3.2%
	Unemployed	5.9%	6.1%	6.3%
Inactive	Students	34.6%	32.5%	34.1%
	Household	49.1%	59.1%	52.9%
	Retired	14.6%	7.6%	11.7%
	Disability	1.8%	0.8%	1.4%
Education	None	6.4%	12.1%	7.9%
	Primary school	18.5%	22.3%	20.2%
	Secondary school	33.5%	37.8%	35.4%
	Higher	41.5%	27.8%	36.4%

Table 4-4: Information on employment and education in Federal District, Estado de México and MCMA (INEGI, 2013a).

Environmentally, the MCMA produces high emissions levels, as Table 4-5 shows. This ranks Mexico City amongst the most polluted cities in the world (Parry and Timilsina, 2010). This is partly caused by MCMA's geographic location. The MCMA is situated in a former lake basin at 2,240 meters above sea level and is surrounded by several mountain ridges. This results in the containment of many pollutants emitted on a daily basis, because the mountains function as a barrier (Valdés-Parada et al., 2012), see Figure A-4 in Appendix C. This effect also causes the pollutants to be concentrated in several areas, see Figure A-5 in Appendix D for the distribution of PM_{10} within the MCMA, which clearly shows that highest PM_{10} concentrations are in the northern boroughs of the MCMA. This problem is significantly related to transport as over half of Mexico City's energy consumption is transport-based (Banister, 2011). Additionally, Mexico City's altitude causes engines to function less efficiently, increasing emission factors by 47% compared to low altitudes (Breakthrough Technologies Institute, 2012). This causes transport to be responsible for 70% of all emissions in the MCMA (Comisión Ambiental Metropolitana, 2011). The percentages of emissions that are transport-based are shown per pollutant in Table 4-5. These pollutants are mainly emitted between 6 a.m. and 10 p.m., as Figure A-6 in Appendix E shows. However, due to old vehicle replacement, cleaner fuels and mandatory use of catalytic converters, pollutant concentrations have decreased in recent years (Islas Rivera et al., 2011). Figure A-7 in Appendix E shows the concentration of several pollutants over time, which illustrates a significant decrease in 2009 compared to 1990 levels.

Pollutant	Average emissions (ton/week)	Average emissions (ton/day)			Transport-based
		Working day	Saturday	Sunday	
PM_{10}	452	67	63	54	16.1%
$PM_{2.5}$	102	15	14	13	51.8%
SO_2	130	21	14	11	49.3%
CO	30,135	4,284	4,571	4,144	99.0%
NO_x	3,622	519	541	486	82.4%
COV	11,217	1,666	1,557	1,330	31.3%
CO_2	889,824	-	-	-	48.0%

Table 4-5: Emissions per day of the week in the MCMA (Comisión Ambiental Metropolitana, 2011).

Pollution is not the only environmental concern in Mexico City, since climate change will result in less precipitation and consequent water shortages. This means an increasing part of the population will have a lack of water availability. Furthermore, due to groundwater extraction, land subsidence is likely, resulting in construction issues (UN-Habitat, 2011). Areas most vulnerable to hydrological changes due to climate change are the least developed, poorer boroughs, such as Tláhuac and Iztapalapa. In fact, in the past 30 years the average temperature has already increased by 2°C in Mexico City (Ciudad de México, 2013b). Mexico City's CO_2 emissions significantly contribute to global warming, with annual emissions of over 43 million tons, of which almost half is transport-based (see Table 4-5).

In the entire MCMA 21.9 million daily trips are made, of which the majority originates from the Federal District (58.4%). This is the result of one of four trips originating from the Estado de México is directed to the Federal District, while vice versa this is only one in six trips (Ciudad de México, 2007). This can be explained by the Federal District being the main employment center of the MCMA. This is confirmed by the number of internal trips, which is higher in the Federal District than in the Estado de México. The trip attraction, production and internal trips are shown in Table 4-2 for each borough of the Federal District. The majority of the trips is work-related (54.2%), while other motives are education (17.8%), visiting family or friends (11.2%), shopping (9.9%), recreation (5.7%) or eating (1.2%). Figure A-8 and Figure A-9 in Appendix F show the number of trips per 15 minutes for, respectively, the entire transport system and public transport. This shows that for both the entire transport system and public transport the morning peak is the most significant and occurs 6 a.m. and 9 a.m. peaking between 7 a.m. and 8 a.m.. There also is a minor afternoon peak, but the evening peak is more significant, occurring between 5 p.m. and 8 p.m..

Income group	Households	Car ownership
0-1 minimum salaries	222,140	0.204
1-3 minimum salaries	1,444,426	0.299
3-5 minimum salaries	1,270,944	0.428
5-10 minimum salaries	1,285,351	0.720
10-20 minimum salaries	523,777	1.258
20-30 minimum salaries	103,365	1.529
>30 minimum salaries	93,750	1.584
Total	**4,943,753**	**0.589**

Table 4-6: Car ownership per household per income group (Ciudad de México, 2007).

Table 4-7 shows the modal split for the MCMA based on the latest O/D survey, dating from 2007. It has to be noted that since then the number of Metro users has increased from around three million to almost five million daily users (STC, 2013a). For the Metrobús, the number of daily passengers has increased from 175,000 in 2007 to almost 700,000 in 2012 (Metrobús, 2013a). The table shows that over two thirds of trips are made by public transport and just over a fifth by car. The mode 'combi, micro and autobus' comprises all privately-owned public transport, consisting mainly of small- and medium-sized vans and buses. Mexico City's O/D survey shows that of the public transport trips 45.1% of the trips use several modes (Ciudad de México, 2007). Of these public transport users, the majority is low-income and on average 36% of this income is spent on public transit fares (Ciudad de México, 2013b). Interestingly, the table also shows that of all transport-based emissions cars are the largest emitters, except for particulate matter. Hence, cars pollute significantly but only transport a limited number of travelers. It is important to note that car ownership is much higher for high-income groups than low-income groups (see Table 4-6). Thus, the rich minority is responsible for the majority of air pollution and GHG emissions in the MCMA. Another notable difference in car ownership is between the Federal District and the Estado de México, who respectively have a car ownership of 0.522 per person and 0.276 per person (INEGI, 2013b). Hence, more of the air pollution is the result of inhabitants of the Federal District, while pollutant concentrations are highest in the Estado de México.

Transport mode	PM_{10}	$PM_{2.5}$	SO_2	CO	NO_x	COV	CO_2	Modal split
Cars	26.4%	19.4%	53.9%	47.9%	42.3%	54.1%	55.2%	20.7%
Taxi	4.7%	3.4%	9.7%	12.3%	13.5%	7.8%	9.8%	5.9%
Combi, micro, autobus	12.6%	14.0%	17.9%	16.5%	25.0%	14.7%	19.8%	55.4%
Truck	53.9%	61.3%	15.7%	13.3%	17.9%	9.3%	13.3%	-
Motorcycle	2.3%	1.9%	2.7%	10.0%	1.1%	14.1%	1.7%	0.3%
Metrobús	0.1%	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%	0.8%
Metro	-	-	-	-	-	-	-	13.6%
Bicycle	-	-	-	-	-	-	-	1.4%
LRT	-	-	-	-	-	-	-	0.4%
Trolley bus	-	-	-	-	-	-	-	0.7%
Other	-	-	-	-	-	-	-	0.9%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table 4-7: Emissions per transport type (Comisión Ambiental Metropolitana, 2011) and modal split (Ciudad de México, 2007).

4.2.2 POLITICAL CONTEXT

In 1981 Mexico City's mayor revoked all public transport concessions owned by private operators and the government took control of all public transport in the city. However, the high subsidies needed to maintain the system quickly gave rise to problems and informal operators owning low-capacity *colectivos* (such as vans and microbuses) started operating again (Flores and Zegras, 2012). These experienced such rapid growth that between 1972 and 1988 their trip share increased from 3.3% to 32%, while the bus trip share dropped from 50% to 19%. By 1988 around 100,000 *colectivos* were driving in the MCMA (Flores, 2013). However, they also resulted in increased congestion, pollution and accidents. Even though the option was politically and financially convenient, it significantly weakened the government's ability to plan public transport. Hence, in the 2000s Mexico City had over 100 organizations representing independent microbus owners and the government was spending much time on mediating conflicts instead of transport planning (Flores and Zegras, 2012).

Currently the public transport system of Mexico consists of a Metro network, commuter train, five BRT lines, trolley buses, a light rail line, a city bus network (Red de Transporte de Pasajeros, RTP) and over 30,000 operators in the privately owned bus network. Private operators run a vehicle fleet of over 300,000 vehicles, consisting of buses (18.9%), minibuses (13.5%) and vans (67.6%) (López Dodero, 2013). This enormous fleet results in major congestion problems, with average travel times increasing from 52 minutes in 2007 to 81 minutes in 2009 (Tarriba and Alarcón, 2012), especially increasing commute times for low-income groups and amounting to 3.3 million lost man-hours per day (López Dodero, 2013). Some low-income neighborhoods require over two hours of travel between work and home. Average travel speeds decreased significantly as well, from 38 km/h in 1990 to 17 km/h in 2007, resulting in economic losses of 4.6% of GDP. Air pollution annually causes 4,000 premature deaths and 2.5 million lost working days due to sickness. A total of 13,000 annual road accidents occur (Ciudad de México, 2013b). This has resulted in great dissatisfaction among public transport users: 65% indicate bad quality, 70% too slow transport, 80% insecurity and 90% uncomfortable travel (Tarriba and Alarcón, 2012). Meanwhile, 80% of public funds is spent on car-oriented projects, while only 11% is spent on public transport, even though the latter represents the majority of trips in the city (López Dodero, 2013).

Despite all these developments, the local government is implementing policies to improve the social, environmental and transport situation. A development plan for Mexico City for the 2013-2018 period was written, in which the government has set the objective to significantly reduce the number of people living in extreme poverty. Furthermore, improvement of the equality between social groups is advocated, as well as the development of infrastructure improvements in the eastern parts of the city to improve equity within the city (Ciudad de México, 2013b).

The development plan also incorporates several environmental goals. First of all, the air quality should be improved by reducing the emission of pollutants. Secondly, the impact on climate change should be reduced, as well as the related risks (Ciudad de México, 2013b). These goals were also already part of Mexico City's Green Plan from 2007 (SEDEMA, 2007), indicating that these are on-going goals of the city. A plan to improve the air quality in the MCMA between 2011 and 2020 also focuses on reducing emissions (Comisión Ambiental Metropolitana, 2011). All these plans indicate that the local government is aware of the impacts of climate change and especially air pollution and is willing to improve this situation.

The development plan also mentions some transport objectives for Mexico City. The government aims for multimodal transport, which is stimulated by, for example, the construction of bicycle parking at mass transit stations. Non-motorized transport is to be further stimulated through campaigns advocating walking, bicycling and public transport. Furthermore, the public transport network is to be improved and enlarged and the microbuses are to be replaced by medium- and high-capacity vehicles. As part of this restructuring, unauthorized public transport and taxis are to be removed (Ciudad de México, 2013b). The Green Plan also focuses on improving the public transport service and a reduction of the number of vehicles on the road (SEDEMA, 2007). Comisión Ambiental Metropolitana (2011) proposes similar plans by regulating the energy consumption in the MCMA, mainly through intermodal transport, promotion of medium- and high-capacity public transport, better transfers and connections and the promotion of bicycle use.

4.3 METRO

In 1969 Mexico City's first Metro line was implemented. Since then, the network has expanded to twelve lines and 226 rail kilometers, of which 197 kilometers are actually used to transport passengers and the rest for maintenance etc. (STC, 2013b). A map of the Metro network is shown in Figure A-10 in Appendix G. The length of each line, number of stations and daily number of passengers boarding the Metro at each line is shown in Table 4-8. On average, the Metro transports 4.7 million daily passengers, serving mainly the central and northern parts of the city (Solis Hernández, 2012). The Metro passengers are mainly low-income citizens, with average wages 15% lower than bus users and 70% lower than car users (Crôtte et al., 2009). Of these passengers about 8.8% does not pay the fare, because free access is granted to disabled people, children under five years and elderly (STC, 2013a).

Line	Length (km)[1]	Stations[1]	Daily passengers[2]
1	18.8	20	766,718
2	23.4	24	825,723
3	23.6	21	691,120
4	10.7	10	83,859
5	15.7	13	239,139
6	13.9	11	139,527
7	18.8	14	274,957
8	20.1	19	363,560
9	15.4	12	341,368
A	17.2	10	249,988
B	23.7	21	467,458
12	24.3	20	272,004
Total	**225.7**	**195**	**4,715,423**

Table 4-8: Properties of Metro lines.

Recently, the discussion was raised to increase the fare of Mexico City's Metro. Historically, Mexico City's fare has been extremely low. In fact, only the metro of Caracas has a fare comparable to Mexico City's fare of three pesos (US$ 0.23). However, the actual costs of a Metro trip are 10.6 pesos (US$ 0.80), which means that the government of the Federal District subsidizes each trip with 7.5 pesos (STC, 2013c). Meanwhile, service has deteriorated with almost two thirds of the passengers having to wait at least one train before they can board. Furthermore, over a hundred trains are out of service due to major maintenance that is required. As a result, a fare increase to five pesos (US$ 0.38) was proposed to the Metro users. A user survey was conducted by three companies on November 28th and 29th and December 2nd. A total of 7,200 users were surveyed. A slight majority of 55.7% was in favor of increasing the Metro fare if the additional incomes were used to improve the service quality (Consulta Mitofsky, 2013; Covarrubias y Asociados, 2013; Parametría, 2013). STC has made promises to improve train maintenance, restrict informal sales within the Metro, improve security, install additional escalators, reincorporate the out-of-service trains, buy additional trains for line twelve and improve air-conditioning (STC, 2013c). Furthermore, some social groups are excluded from this fare increase. As a result, female household heads, students and unemployed citizens living in the Federal District will still pay three pesos. For the rest, the flat fare was raised to five pesos on the 13th of December 2013 (STC, 2013b).

Metro line twelve is the newest line and began operation on October 30th, 2012. The line has a length of 24.3 km, running between terminal Mixcoac, south of the city center, and terminal Tláhuac, in the southeast of the city. The Metro line passes the boroughs Tláhuac, Iztapalapa and Benito Juárez. The former two are amongst the poorest boroughs, while the latter is among the most prosperous boroughs. The Metro line connects with Metro lines 2, 3, 7 and 8 (Spectron Desarrollo, 2009). Spectron Desarrollo (2009) highlights that the main objectives of the Metro line are to reduce daily travel times, improve network connectivity, increase equity and reduce emissions.

Line twelve serves a total of twenty stations, of which nine are underground stations, one is on ground level, and ten are elevated (STC, 2013b). Of these stations Tláhuac, Periférico Oriente,

[1] STC (2013b)
[2] STC (2013a)

Insurgentes Sur, Tezonco and Nopalera have the largest passenger flow, while Tlaltenco, Eje Central, Lomas Estrella, Ermita and Parque de los Venados have the smallest passenger flow (STC, 2013a). However, it should be noted that in these passenger flows only the number of passengers entering the Metro system at a station are included. Hence, on transfer stations, the number of passengers entering the line is expected to be higher. Currently, on average 272,000 daily passengers are boarding the Metro at line twelve, while an average of 430,000 daily passengers use the line (STC, 2013a). Hence, a total of 158,000 users transfer from other lines. Initially, a total of 385,000 daily users was expected (Ciuded de México, 2013).

A visit to Metro line twelve provided some insights in how the line is currently functioning. This visit was made on the 4th of November during morning peak (7 a.m. to 11 a.m.) and afternoon peak (5 p.m. to 7 p.m.). First of all, the Metro system is accessed using a paper ticket or a chip card that can be used for Metrobús, RTP and the light rail. Secondly, there is a clear difference between morning and afternoon peak, with the majority of passengers travelling in the direction of Mixcoac in the morning, while in the afternoon the majority travels in the direction of Tláhuac. Thirdly, there are some transfer stations which require a long transfer. Most notable are Ermita (transfer to line 2), which requires significant vertical movement and Atlalilco (transfer to line 8), which requires significant horizontal movement of ten to fifteen minutes. Fourthly, terminal Tláhuac provides a transfer from other transportation modes, such as local buses. A bus terminal was planned for this, but is currently still under construction, which means that at the moment all buses stop on the street, occupying at least one traffic lane. Fifth of all, during peak hour the facilities to transport passengers from the platforms to the station are not always sufficient. Especially escalators tend to become busy and queuing occurs. Passenger flows are also not organized most efficiently, especially because to decrease walking distance passengers ignore the 'no passing' signs, but thereby conflict with other passenger flows. Finally, sometimes directions are unclear and only few maps of the Metro network are present within the station and on platforms.

4.4 METROBÚS

This section discusses Mexico City's BRT system, the Metrobús. First, the history of how the BRT system was implemented is given. After that, some properties of the Metrobús line studied in this research are discussed.

4.4.1 HISTORY

In 2005 another high-capacity transit system was introduced, the BRT system named 'Metrobús', which stretched 20 kilometers along one of Mexico City's principal north-south routes; Insurgentes Avenue (Wöhrnschimmel et al., 2008). On this corridor travel speeds increased from 12 km/h to 17 km/h for general traffic and to 20 km/h for the Metrobús. Additionally, accidents on Insurgentes Avenue decreased by 84% between 2005 and 2010 (Solis Hernández, 2012). Since then, four additional BRT corridors have been constructed. The total length is currently 105 kilometers of bus way, serving 163 stations with over 400 buses. No official feeder services exist. In total, an average of 855,000 daily passengers are transported at 19.5 km/h (ALC-BRT and EMBARQ, 2013). Of these passengers, 17% previously used a car (Solis Hernández, 2012). Another three lines are planned by 2015, increasing total network length to 150 km and a total network of ten lines is planned. The main objective of Metrobús is to reduce travel time, GHG emissions, accidents, air pollution and noise (NYC Global Partners, 2012).

The implementation of the Metrobús was not easy. Existing bus operators opposed its implementation, because they were afraid to lose business (Flores and Zegras, 2012). López Dodero (2013) finds that drivers owning a single bus and operating privately were less willing to cooperate than concession lease operators with a larger vehicle fleet. Flores and Zegras (2012) discuss force and foster approaches. In the former recumbent bus operators are forced out of operation, while the latter focuses on participation of recumbent bus operators in providing transport on the newly developed BRT corridor. The first two Metrobús lines were implemented using a fostering approach, in which existing operators were involved in the planning of the BRT and were paid a fixed amount per provided service kilometer. In fact, the first BRT corridor was partially selected based on minimization of opposition and compensation for existing bus operators. The existing operators own and operate the BRT buses and their individual revenues were calculated in such a way that they matched previous revenues. However, this was only possible if the publicly-owned RTP participated, who received lower compensation and thereby indirectly provided a subsidy to the privately-owned bus operators. In the end, it was said that arriving at agreeable revenues was considered 95% of implementation, because construction was easy (Flores, 2013).

Due to high costs per service kilometer, the third BRT line used a more force-oriented approach, resulting in mobilization by recumbent operators against the project. The RTP was no longer participating and the compensation for operators per vehicle kilometer was diminished. This suggests that initially part of the compensation was paid to foster private operators. This illustrates the trade-off experienced between political feasibility and economic efficiency. The fourth Metrobús line only involves four shareholders, indicating a further shift towards a more forceful approach. However, a significant subsidy is still required due to an overestimation of the number of users. Overall, Metrobús operates with a yearly deficit, which in 2011 amounted to approximately 0.72 pesos per passenger, or US$ 9.7 million per year. On a more positive note, this has resulted in a shift from 900 microbuses to 230 bi-articulated buses, reduced travel times, lower pollutant emissions, safer and more reliable trips and fewer traffic accidents (Flores, 2013).

López Dodero (2013) notes that the time span of political appointments (typically six years in Mexico) limits the options of public transport planning, because projects have to be finished within this period. Thus, not only social costs and benefits, but also the political feasibility and time span of the project, influence the decision making process. Hence, including existing bus operators in this process improves the political feasibility of public transport projects. Interestingly, these bus operators are less concerned by a Metro system, because they do not regard it as a competitor, making Metro systems politically more feasible for bus operators, although implementation time is longer and construction costs are higher.

4.4.2 METROBÚS LINE FOUR

In April 2012 the fourth Metrobús line began operation. The line is 28 kilometers long and serves a total of 37 stations, of which four are terminals. The line connects with line 1, 3 and 5 of the Metrobús system, line 1, 2, 3, 4, 8 and B of the Metro and the commuter train (Metrobús, 2013b). A map of the entire Metrobús network is shown in Figure A-11 in Appendix H. The main reason for the construction of line four was that there was no existing public transport service connecting Buenavista, San Lázaro, the historic center and the international airport (SOBSE, 2011). The line therefore provides its main service between the Buenavista and San Lázaro (which is also a long-distance bus terminal) terminals, but some buses also continue to the international airport of Mexico City. Hence, line four provides a connection between the historic city center and the airport, passing through the boroughs Venustiana Carranza and Cuahtémoc. The most important characteristic of this line is that to pass through the historic center, short (12 meter), non-articulated buses are used. As a result, except for the terminals, all stops are in the form of regular stops, sometimes with a platform, instead of stations. Hence, fare payment (six pesos; US$ 0.46) occurs when entering the bus, using the electronic chip card also usable for the Metro (Ciudad de México, 2011). Hook (2005) identifies such a system as an open BRT system and states that such systems have a lower capacity than closed BRT systems (with off-board fare collection). Hence, line four cannot be considered a full BRT line and therefore impacts may be smaller.

Ex-ante studies show that the expected demand for the corridor was 43,300 passengers per working day (SOBSE, 2011). This is based on a supply and demand study, which shows that 585,000 trips occur within the zone of influence of the Metrobús line. However, only 16% of these (over 105,000) can actually shift to Metrobús, because the majority of the trips occurs using the Metro and only pass the corridor. The study also showed that the majority of passengers used some combination of microbus, walking and Metro, in which the former two were access and egress modes, while the latter was the main leg of the trip (CETRAN, 2009). When operation started, it turned out the number of passengers was overestimated, as there are only 31,000 passengers per working day (CTS Embarq, 2012). However, currently the number of passengers per working day has increased to 59,344 (Metrobús, 2013a). A similar increase in passengers occurred for the first Metrobús line, which increased from 230,000 in 2005 to 440,000 in 2012 (López Dodero et al., 2013).

The main objectives of the construction were to reduce travel times by at least 40%, attain a modal shift from private vehicles, improve integration with other transport modes and to offer supply for trips destined to and originating from the eastern bus terminal, airport, historic center and suburban train (GDF, 2014b). To achieve this, a CBA was carried out, but this analysis only incorporated financial costs and benefits, comparing the costs of the BRT line with an alternative situation in which other improvements had to be made, which showed the BRT line provided a NPV of 545 million pesos (almost US$ 42 million) (SOBSE, 2011). Another impact study shows that reductions are expected for CO_2 (23%), PM (14%), NO_x (18%) and CO (29%) emissions, a 17% modal shift from car to Metrobús and travel time savings of 40% (Ciudad de México, 2011). Finally, it is expected that in total over 840,000 people are (directly and indirectly) impacted by the construction (Cinco M Dos, 2013).

A visit to the Metrobús line provided some insights in its performance. This visit was made on the 6th of November, during morning peak (7 a.m. to 11 a.m.) and afternoon peak (5 p.m. to 7 p.m.). First of all, the line is constructed in a circuit, with a northern and southern route which both are bidirectional. Hence, actually two BRT lines are provided. Secondly, the route serving the airport is more expensive (thirty pesos compared to six pesos for the regular BRT). As a result, buses serving the airport only transport a few passengers, because those not going to the airport do not want to pay the additional fare. Thirdly, passengers waiting to board queue in a line, something that does not happen at other Metrobús lines or the Metro. Fourth of all, the fare is paid upon entering the bus, which has several implications. To check that this occurs correctly, every stop has a police officer that checks if passengers pay upon boarding and that they do not enter in the back without paying. Also, this means that boarding occurs much slower because boarding only occurs in the front of the bus and passengers do not always continue to the back, blocking the entrance. Fifth, the stations that are terminals have doors on the platform, but these are open whether there is a bus waiting or not. Sixth of all, the first section from San Lázaro of the south line does not have a segregated bus lane. Seventhly, at street crossings no traffic light prioritization exists, which means the buses often have to wait along with regular traffic. Eight of all, there is no route information within the bus, meaning that people can only see where the bus stops at the stops themselves. Ninthly, the transfer terminals are not integrated, which means that the Metrobús system has to be left and entered again at the terminal for a different line. However, the electronic chip card does ensure that transfers between Metrobús lines are free. Finally, the route entails many turns and drivers often accelerate and decelerate abruptly, making the on-board comfort for standing passengers far from ideal.

4.5 CONCLUSIONS

This chapter has provided a lot of information on the organization of transport in Mexico in general and in Mexico City in specific. Furthermore, it gives some insights in the Metro and Metrobús systems of Mexico City, which are studied for this research. The literature studied for this chapter shows that significant income inequalities exist in Mexico. These income inequalities are also present in Mexico City, although these are smaller than the national average. Nonetheless, still over a quarter of the population of the Federal District is living in poverty, while almost half of the population of the Estado de México is living poverty. Besides these social issues, Mexico City still experiences high levels of air pollution, even though improvements have been made in recent years. Furthermore, CO_2 emissions are high, while Mexico City itself is vulnerable to climate change as well. The transport sector is the largest emitter of pollutants and GHGs. Especially cars are responsible for these emissions, while they represent only a marginal modal share. Over two thirds of the trips in Mexico City are made by public transport, the majority of which is made using small microbuses. The enormous amount of small public transport vehicles have led to increases in congestion, low travel speeds and increased travel times.

Mexico City has undertaken some initiatives to decrease inequality, improve the environmental sustainability and the transport organization of the city. For this purpose several development plans have been constructed. Transport-wise, Mexico City's government mainly aims at non-motorized transport and mass transit solutions, as a replacement of less efficient small- and medium-sized public transport. The main mass transit system in Mexico City is the Metro, which transports almost five million daily passengers. The newest Metro line is the golden line twelve, which serves some of the poorer areas of the Federal District. The effects of this line are evaluated in this research. A more recent high-capacity transport system which has been introduced to Mexico City is the BRT system named Metrobús. The introduction of this system has resulted in significant resistance among existing bus operators and implementation has not been easy. However, currently five lines are in operation. The fourth line, running between the airport and the historic center, is the focus of the BRT evaluation of this study.

CHAPTER 5. METHODOLOGY

This chapter discusses the methodology applied to conduct the research. First of all, the evaluation framework is developed. This mainly regards the analysis assumptions and the steps required to perform the analysis. Secondly, the indicators that are used in this study are selected. Thirdly, the data collection methods are addressed, which depend on the indicators selected previously. Fourth, the methods used to calculate the indicator outcomes are discussed. Fifthly, the indicator aggregation method is elaborated on. Finally, the sensitivity analysis is explained.

5.1 EVALUATION FRAMEWORK

The main challenge of this research is to find an appropriate analysis for ex-post evaluating transport projects in developing countries. To do so, first of all the analysis assumptions are addressed. This paragraph focuses on which assumptions form the basis of the analysis. The second paragraph discusses step-by-step how the analysis is conducted.

5.1.1 EVALUATION ASSUMPTIONS

Most previous research focuses on ex-ante project appraisal and particularly cost-benefit analyses. Even though methodically ex-post evaluations differ significantly from ex-ante appraisal, there are also many similarities. The literature review illustrates that ex-ante appraisal methodology can definitely be adjusted to be applicable to ex-post evaluation. However, this does not necessarily mean that an approach comparable to CBA is most suitable for developing countries and BRT and MRT systems.

The literature review showed that on a global level GHG emissions are a major issue, which poses serious threats through global warming. Especially developing countries are vulnerable to this, because their large cities are located in areas prone to natural disasters and also have limited adaptive capabilities. Furthermore, income inequalities are prevalent and of major concern, as well as the growth of slums. Hence, besides environmental concerns, also social matters are troublesome. The literature review shows that in Mexico City mainly social issues prevail, illustrated by great income inequalities. Although pollution has decreased over the past years, this still poses a serious health threat to citizens.

Thus, it is required to represent these social and environmental concerns in transport evaluation. The literature review shows that one of the major issues with CBA is that social and environmental effects are difficult to quantify and even more difficult to monetize. This often leads to social and environmental effects not being incorporated sufficiently in those analyses. Furthermore, distributive effects are not taken into account, which is of major importance if inequality aspects are to be included. Given the utilitarian approach of CBA and the great income inequalities in developing countries, it is clear that CBA will result in a small high-income group dominating the outcomes of the analysis. This is undesirable for the evaluation, especially because one of the MRT line's objectives is to improve equity. Hence, strong adjustments to the CBA appraisal methodology are required for this ex-post evaluation.

Since the main issue is monetization of social and environmental indicators it is undesirable to monetize all effects. Instead, the effects that are easily monetized and are naturally expressed in money, such as construction costs and travel time savings, are monetized. Other effects that are not logically expressed in monetized terms are presented in their 'original' dimension. For example, it is extremely difficult to put a prize on GHG emissions, so these are better expressed in tons of emitted GHG. This means the evaluation consists of economic effects which are monetized and social and environmental effects which are not monetized. These effects can then be aggregated using the flag model, which provides insights in the sustainability of policy options, by assigning colored flags to each indicator. As mentioned before, the utilitarian approach of traditional CBA is not suitable for social indicators, because few rich people outweigh many poor people. Egalitarian theories are more appropriate as these strive towards a more equal society. Hence, if applicable, egalitarian theories are used for the indicators.

Since the MRT and BRT corridors are not located in the same area, it is difficult to accurately compare the two, because many exogenous effects may influence the impacts as well. For example, changes in the location of jobs may change travel patterns. If this is the case, then additional (or fewer) passengers may use the transport system than originally would have been the case. Fortunately, both corridors have opened recently, which means effects are only marginally distorted by exogenous effects.

Nonetheless, the question remains what would have happened if instead of a BRT corridor, an MRT corridor would have been constructed, and vice versa. For decision makers it is interesting to know which alternative provides more value for money, because funds can only be spent once. Opportunity costs are the costs of choosing one alternative. For example, if one MRT line is preferred, then another MRT line cannot be constructed. The missed benefits from the other MRT line are called opportunity costs. However, for BRT and MRT this is not as straightforward, because construction costs differ significantly, with BRT costing ten to one hundred times less than MRT (Wright and Hook, 2007). Hence, the same budget means a BRT line of ten to one hundred times the length of the MRT line can be constructed. Metrobús line four is 28 km in length, compared to the 24.5 km of Metro line twelve. This means that a direct comparison of effects is unfair, because construction costs of the Metrobús are significantly lower. A solution to overcome this issue is not to look at (economic) effectiveness, but at efficiency. For the economic dimension this means that not the NPV is the best evaluation criterion, but rather the B/C ratio is used, which indicates how much benefits are reaped from each invested dollar. Also the environmental and social dimensions can be expressed this way, by indicating changes per invested dollar (e.g. reduced emissions per invested dollar). This method allows for comparison between the two cases without construction of complicated hypothetical scenarios.

5.1.2 EVALUATION STEPS

The steps required for the analysis are based on the steps used in CBA and ex-post evaluation, with some adjustments to fit the previously made analysis assumptions. First of all, some specifications of the evaluation are set. It is important to decide the geographic extent of the analysis; for example analyzing effects for the Federal District, the entire MCMA or only for neighborhoods within a certain distance of the transport system. In order to express future benefits in current values, a discount rate needs to be specified. In Europe these are often quite low, ranging between 3% and 8%, but various sources indicate that for developing countries in general and Mexico in specific a higher discount rate is preferable. Most Mexican literature suggests using a discount rate of 12%. Another specification is the time span, or project horizon, of the analysis, which determines how long benefits are included in the evaluation. A longer time span increases the total benefits of a project. Both BRT and MRT corridors have long lifetimes, but due to the use of discount rates benefits decline over time. Spectron Desarrollo (2009) uses a thirty year project horizon for the ex-ante appraisal of Metro line twelve, while SOBSE (2011) use a ten year project horizon for the Metrobús line. However, a discount rate of 12% means that effects after thirty years only account for 2.2% of those in the first year. Hence, a project horizon of thirty years is exaggerated. A more suitable time span is fifteen years, which means that effects in the final year are still 15% of the effects in the first year.

In the second step the project effects are estimated. The impacts included in the analysis for Mexico City are discussed in the next section. An example of an impact that is estimated is the total travel time savings of a project. This estimation is often a comprehensive procedure, because data collection is required. However, also some indicators that are easier to estimate are included in this step, such as construction costs. A comprehensive explanation of how the indicators values are calculated can be found in section 5.4.

The second step estimated the project effects and this third step uses these effects to monetize the effects that are included in the economic dimension. This monetization is based on values attributed to certain effects. These values can be based on survey results, but also values found in literature can be used. Furthermore, these values are extrapolated along an appropriate indicator such as GDP or wages, because it can be expected that these values change over time. Moreover, the discount rate is used to express monetized effects in the same value. Expressing all economic effects in financial terms allows easy summation of these effects.

When all project effects are estimated, the indicators are aggregated to produce the outcomes of the evaluation. The flag model is used for this. However, there are some challenges for adjusting the flag model for this research. First of all, the determination of the CTVs is extremely important for the outcomes of the aggregation. Often, these values are based on expert consultation. However, this regularly results in ambiguity in the values, because agreement is not always found. Another option is to use the thresholds from other studies on transport effects. This gives some indication on the range of effects that can occur. Based on these ranges, CTVs can be determined, for example by distinguishing between marginally sustainable, entirely sustainable and unsustainable options. The aggregation of the indicators is thoroughly discussed in section 5.5.

Once all outcomes are known, the projects are compared. This comparison is done in two ways. First of all, the individual indicators are compared. This shows how the projects differ from each other. Secondly, the aggregated indicators are compared. The economic outcomes easily compare, which is best done using the B/C ratio as this expresses efficiency, while the NPV only regards effectiveness. For the social and environmental dimension this is more challenging, because the aggregated outcomes do not indicate economic efficiency. Hence, the outcomes may be twice as good for one project, but investments may have been ten times higher. This means that the money was invested less efficiently. Therefore, the outcomes are also expressed in terms of capital investments. This can be done by dividing the impacts by the construction costs, thereby expressing the outcome in terms of change per invested dollar. This way, the social and environmental outcomes are compared in terms of economic efficiency. Furthermore, the aggregated indicators are compared using the flag model.

In the sixth and final step of the evaluation a sensitivity analysis is conducted. This is done by changing various parameters of the analysis and evaluating the impact this has on the outcome. For example, the effects of changes in the value of time on economic outcome are analyzed, because this is what happens if the estimated value is incorrect. Also variations in equity indicator and emission factors are analyzed. This gives an indication of how incorrect estimations influence the outcome of the evaluation. Parameters are changed separately. The evaluation steps are summarized below:

I. *Evaluation specifications*; this step sets the specific characteristics of the evaluation, including evaluation period, discount rate and geographic scope;
II. *Estimation of project effects*; this step estimates all other costs and benefits of a project, based on collected data;
III. *Monetization of economic project effects*; this step monetizes the economic effects determined in step III, using valuation techniques;
IV. *Indicator aggregation and evaluation outcomes*; this step applies the flag model to aggregate all indicators;
V. *Project evaluation comparison*; this step compares the outcomes of various projects, per indicator and for the projects in general.
VI. *Sensitivity analysis*; this step makes variations in various parameters of the evaluations to investigate how these influence the outcome of the evaluation.

5.2 INDICATOR SELECTION

The literature review discussed many different effects of transport projects. However, some of the indicators were mentioned more frequently than others. Also, some impacts are difficult to measure and not all effects are as relevant for a developing country context as they are for developed countries. For example, comfort is important in the Dutch context, but will be less so in the case of Mexico, since this is subordinate to main indicators such as travel speed, frequency, reliability and affordability. If the main indicators are not fulfilled then factors such as comfort will not play a prominent role. Furthermore, time for this research is limited, which means that not all indicators can be investigated. In order to include a significant number of indicators, passenger surveys have been chosen as the main data collection method. This also implies that data required for indicators has to be collectable using a passenger survey. During the selection process, the aim was to keep at least one social, one economic and one environmental indicator from the indicator list for sustainable development used by OECD (Hass et al., 2002). Additionally, the main externalities of transport in Mexico (congestion, accidents, climate change and air pollution), studied by Cravioto et al. (2013), are regarded as important indicators for the framework.

Below, the indicators that are used for the ex-post evaluation are briefly discussed. First the social indicators (equity and safety), then the environmental indicators (air pollution, climate change and modal shift) and finally the economic indicators (construction and operating costs, revenues and travel time savings) are elaborated on. The indicators are summarized in Table 5-1. For these indicators, both direct and indirect effects are included, if applicable. Direct effects concern benefits that are experienced by users. Indirect effects refer to benefits for travelers not using the transit line, but that are traveling within its zone of influence. These effects are indirect, because they indirectly benefit from the implementation, for example because of fewer vehicles on the road. Some of the indicators mentioned in the literature review that were omitted from the evaluation framework are elaborated on in the final paragraph of this section. This is only done for indicators that are not omitted due to data and time limitations. A comprehensive discussion on how indicators are calculated is given in section 5.4.

5.2.1 SOCIAL INDICATORS

Equity regards the fairness of the distribution of transport project benefits. It is impossible to decide what a perfectly fair distribution is, but in general policies are regarded fair if a project benefits less advantaged groups more than more advantaged groups. If this is not the case, compensation can take place, but this is uncommon in developing countries. Hence, an equitable project is defined as one that distributes more benefits to less advantaged groups. Vertical equity is measured using different income groups, as this is the most common and meaningful indicator. Ideally, all benefits are included in a distributive analysis. However, this is impossible in the time available for the research. For that reason, the distribution of the most significant impact is analyzed. Travel time savings often account for the majority transit benefit and are therefore the indicator over which equity is measured. Thus, the equity indicator will demonstrate how travel time savings are distributed over income groups.

Safety is a major concern for travelers. Unfortunately, accidents occur on a regular basis with varying impacts; from minor material damage to fatal injuries. More congestion and a higher number of vulnerable road users such as pedestrians and bicyclists result in a higher likelihood of accidents. Measuring traffic safety therefore means not only evaluating the number of accidents, but also incorporating the severity of the impact the accidents have. Therefore it is interesting to look at the total number of accidents, the number of light injuries, severe injuries and fatalities. Accidents associated with transit, for example, mainly result in non-fatal injuries (TRB, 2002). This means the damage is much smaller. However, a passenger survey cannot incorporate the actual number of accidents, but only the perception of safety. Therefore, the change in safety perception is measured. Nonetheless, this gives a good indication of safety, because respondents relate to the frequency of being involved in or having seen accidents.

5.2.2 ENVIRONMENTAL INDICATORS

For cities, local air pollution is a severe threat to the health of citizens, but also influences the quality of life, as high emission levels can cause haze and block sunlight. Harmful emissions include NO_x, SO_x, CO and PM. In Europe regulations exist on maximum concentrations of these gases, but in developing countries this is not necessarily the case. However, many developing cities, including Mexico City, have pollutant concentrations that are threatening health. Hence, an emission reduction will improve the quality of life. Air pollution can be measured in terms of tons of each emission gas. These can be estimated using emission factors per transport mode and combining these with modal shifts and changes in travel volumes as a result of a transport project (TRB, 2002).

Climate change is an important global issue and many policies now focus on reducing the emission of GHGs. Hence, determining the effect a transport project has on CO_2 emissions is important. Mexico City's first BRT line on Insurgentes Avenue applied for funding through the Clean Development Mechanism (CDM) and as part of that application had to provide insights in the reduction of CO_2 emissions resulting from the project (Rogers, 2005). This illustrates the importance of evaluating CO_2 emissions in transport projects.

Incorporated in both air pollution and climate change is the modal shift that results from project implementation. However, CTS Embarq expressed a specific interest to incorporate the modal shift in the evaluation framework, because it provides vital insights in which modes the new transit line replaces. Given the resistance of recumbent operators during the planning of the Metrobús corridors, this gives a better comprehension of who actually 'lose', and how much, as the result of the implementation of the two new transit lines.

5.2.3 ECONOMIC INDICATORS

Every transport project requires capital investments for construction. Hence, construction costs are included in the ex-post evaluation. These costs include infrastructure, stations and rolling stock. Infrastructure is only included if this is constructed specifically for the project. If an existing road is used, these costs are excluded (TRB, 2002). For MRT systems this means that rail infrastructure is included. For BRT this depends on if existing roads are transformed to BRT corridors or if new roads are paved particularly for BRT. Besides these fixed costs, the variable costs are also included as economic indicator. System operating and maintenance costs are relevant for every transit project, because salaries, fuel and vehicle and infrastructure maintenance are vital for successful operation.

Besides these costs, transit projects also generate revenues through passenger fares, which are included to comprise all financial expenditure and incomes. Often, tickets are subsidized by governments. However, these subsidies are not included in the analysis, because they are incomes of the transit company (if it is privately operated) but costs for the government. Hence, for society the benefits and costs of these subsidies cancel each other out. If transit is publicly operated, these subsidies are never paid directly. A combination of the operating and maintenance costs (variable costs) and revenues (variable benefits) results in the operating profit (or loss). Public transit is often said to be unprofitable, but interestingly Deng and Nelson (2013) indicate BRT systems can have profitable operation. All the previous three indicators are converted to US dollars per kilometer of infrastructure to allow for comparison with literature.

Travel time savings are related to increased speeds on the network, higher frequencies and faster transfers. For this analysis, both the in-vehicle travel time and waiting times are used to estimate travel time savings. Access and egress times are also part of the analysis, because travelers decide to make slightly longer journeys to profit from the higher speeds on the transit lines. These travel time savings are measured in minutes, but summed to hours. Travel time savings are monetized using the value of time (VOT). These estimates are typically related to income, which is logical for work trips, but less so for non-work trips. A reasonable average for the value of travel time is 50% of the gross wage rate (TRB, 2002). However, this means that travel time values increase along with income, which is undesirable for unequal societies. Hence, this analysis uses two principles to monetize travel time savings; one based on an equity value of time (equal for everyone) and one based on income (aggregated into several income groups). This way, differences between the two approaches can be shown. Since the value of money changes over time, so will VOTs. To compensate for this effect, the value of time is extrapolated along with GDP.

Indicator group	Indicator	Dimension	Data	Future values
Social indicators	Equity	-	Income groups, travel time savings	-
	Safety	Qualitative	Safety perception	-
Environmental indicators	Air pollution	Tons of gas/km/year	Emission factors, traffic volumes changes	-
	Climate change	Tons of CO2/km/year	Emission factors, traffic volume changes	-
	Modal shift	% per mode	Previous transport mode	
Economic indicators	Construction costs	US$/km	Construction costs	-
	System operating and maintenance costs	US$/km	Salaries, fuel costs, maintenance costs etc.	-
	Operating revenues	US$/km	Number of tickets sold	-
	Travel time savings	Hours, US$/year	Travel time savings, average wages/value of time	GDP

Table 5-1: Indicators used in research, grouped in social, economic and environmental dimensions.

5.2.4 OMITTED INDICATORS

Many indicators discussed in the literature review have been omitted from the framework discussed above. A few of these are discussed here, but only those indicators that are most significant in other evaluation studies and are not omitted solely because of data and time restrictions.

Social exclusion is not part of the analysis, because this concerns the participation in activities. This means that the entire trip chain, including origins and destinations, has to be accounted for. Hence, an extensive analysis is required to estimate if people are socially included due to the transport project. This extensive analysis, requiring advanced GIS modeling is considered outside the scope of this research.

Travel time reliability is an indicator often used in the European context. However, in Mexico City frequencies are high so no timetables are used. This means that vehicles cannot be delayed, unless the entire system breaks down. Since this is a rare occurrence, this is not included in this research.

Land value changes were mentioned a few times in the literature reviewed. The main reason this has been omitted is that it is difficult to attribute these changes to a change in a transport system, because many other variables also affect land values. Furthermore, these are long-term effects so evaluating them a few years after implementation will not yield significant results. Furthermore, incorporating land value changes would comprise a thesis on its own.

5.3 DATA COLLECTION

Section 5.2 discussed the indicators that are used. Also, some information was given on what data is required to make these estimations. How this data is collected is discussed in the first paragraph of this section. The second paragraph briefly describes the survey design. The third paragraph discusses the required sample size of the passenger survey.

5.3.1 DATA COLLECTION METHODS

For this research, the main data collection method is passenger surveys. This method is chosen, because this offers most possibilities to collect data on the two most important indicators; travel time savings and equity. A relatively simple passenger survey already has the ability to collect data on all the indicators within the evaluation framework. Recently, CTS Embarq conducted a survey among Metrobús users. This survey was conducted by an external company among 1,562 respondents. The results were presented by Emporia (2013) in October 2013. Of all surveys, 369 were conducted at stations of Metrobús line four, which are useful for this research. The survey contained some questions specifically designed for users of line four, such as questions about current and previous travel time. Hence, the data acquired by this survey are used for this study. The Metrobús survey is shown in Appendix M.

Besides the Metrobús survey, data is required for the Metro users as well. As no data is available on this, a new survey is constructed. However, the Metrobús survey format is used as basis to ensure that results are comparable. Besides a survey for Metro users, it is important to address indirect effects on travelers in the same zone of influence, not using the transit line. These comprise all travelers that travel within the zone of influence of the Metro and Metrobús system, but that do not use these systems. Basically, this encompasses all trips that are made on parallel streets, especially on major arterial roads. Hence, a survey for Metrobús non-users and a survey for Metro non-users are constructed. The design of these surveys is discussed in section 5.3.2.

Public information is consulted to gather information on construction costs. Annual reports of public accounts are published and these include construction costs of both Metro and Metrobús. Furthermore, studies conducted by CTS Embarq provide insights in operating and maintenance costs. In combination with public information, these are used to determine the operating and maintenance costs of both transit lines. Additionally, public information and studies of CTS Embarq are used to determine the total number of passengers and the number of passengers per station, which is required for respectively the revenue calculation and the data expansion.

Additionally, the Metrobús organization is consulted to provide some data that cannot be collected using surveys or public information. This organization can provide data on maintenance and operating costs. If available, further breakdowns into salaries, fuel and maintenance costs are interesting for the comparison, but not a requirement. Furthermore, this organization can provide some useful insights in the political context of the construction of new public transport lines. They can also provide perceptions on project objective attainment. A list of the questions addressed in the Metrobús interview is shown in Appendix J. On the 22nd of January 2014 the Metrobús was visited. This included of a visit to the 'Centro Informativo de Transporte Inteligente' (Information center on intelligent transport), where all of the operation for Metrobús is managed. Furthermore, this offered the possibility to ask questions to Félix Santiago, in charge of the technical coordination of the Metrobús, and Gonzalo García Miaja, assistant director of new technologies and emission reductions. Unfortunately, it proved impossible to visit the Metro authorities and therefore no further information on the Metro system could be collected.

Finally, interviews with local transport specialists are conducted. These are not used to collect data for the evaluation framework, but to provide insights in the organization of public transport in Mexico City. Also, their opinion on the policy objective attainment of the two transit lines is discussed. Moreover, specialist consultations are useful to provide feedback on the indicators that are used in the framework and on the usefulness of such a framework in the Mexican policy context. A list of the questions asked during the interviews is shown in Appendix K. The first transport specialist interview was conducted on the 18th of January 2014 with Emelina Nava, who works in transport planning at 'el Colegio de México'. The second transport specialist interview was conducted on the 23rd of January 2014 with Onésimo Flores, who is a lecturer in urban planning and design at Harvard University and has conducted his PhD at MIT on BRT implementation in Mexico City. An overview of the collection methods, the data that is collected using the methods and for which indicators the collection method is useful is shown in Table 5-2.

Collection method	Data collected	Indicators
Passenger survey	Travel time, income, modal shift, trip generation, income-dependent value of time, safety improvement	Travel time savings, equity, safety, air pollution, climate change
Metrobús organization	Operating and maintenance costs, objective attainment, political context	System operating & maintenance costs
Transport specialist consultation	Objectives met, evaluation, political context	-
Public information	Construction costs, operating and maintenance costs, revenues	Construction costs, operating and maintenance costs, revenues

Table 5-2: Overview of data collection methods, what data is collected and for which indicators data is useful.

5.3.2 SURVEY DESIGN

The literature on the survey design process was already discussed in section 3.6.1. This section focuses on how the surveys for the Metro users and Metro and Metrobús non-users are designed. First of all, the problem is defined. For this research, the desired state is a sustainable transport system, in social, economic and environmental terms. Currently, congestion, unequal access and air pollution are causing unsustainability in the transport system. Hence, the problem can be defined as congestion, inequity and air pollution causing undesirable characteristics of the transport system, such as lost working-hours, health risks and unequal access to opportunities. Given this problem, the main goal of the community, i.e. the population that is affected by this problem, would be to diminish air pollution, reduce congestion and improve the equality in access to opportunities. This research focuses on how the new MRT and BRT lines contribute to achieving the desired state of the transport system. Thus, how the time lost in traffic is reduced, how health risks have decreased and how access to (income) opportunities has become more equal. Of course, it may also be possible that instead of an improvement the system has deteriorated.

Next, the system boundaries are set. For this survey no clear social boundary exists, because both the users and non-users are of interest. However, for the Metro passenger survey the social boundary is users and for the Metro and Metrobús non-user survey, the non-users are the social boundary. The spatial boundary of the analysis is clear, because only the effects on a certain corridor are considered, and not the effects of the entire network. Hence, the user survey concerns the transit corridor, while the non-user survey concerns the parallel road corridor. The temporal boundary is the period between the opening of the new transit line and the present.

The main survey objective is to collect data for estimation of the social, economic and environmental effects of the new transit lines. This objective can be further specified into data collection on travel times, income, modal shift, previous vehicle use and perception of safety. Some further data collection is required for data expansion. This data mainly concerns the characteristics of the population. With the objectives set, the literature study was consulted to ensure that the information that is gathered is new information, which is the case. Furthermore, literature has been studied to find some information on the results that can be expected. Since this information is most important for the indicator aggregation, this is thoroughly discussed in section 5.5.

In order to prevent confusion, three key terms for the survey are defined below:

- *Trip*
  This is the most important definition of the survey. For this survey, a trip relates to the entire

one-way linked trip from door-to-door. This means that a trip is the journey from origin all the way to destination and can consist of several transportation modes. Thus, a person walking from home to the Metro, then taking the Metro to another station and then walking to work is considered one trip. The return trip (from work to home) is considered a new trip. The reason linked trips are used is because the research focuses on travel time savings. Hence, if previously someone traveled from home to work using one mode and now uses several modes because of a modal shift, then the travel time savings are the difference in travel time between the previous and current travel time from home to work. Comparing only in-vehicle time would disregard the change in access and egress travel time. However, if the new Metro line would offer faster travel speeds and passengers are willing to walk longer to access the system, then these changes in travel time also need to be incorporated. Therefore, the entire linked trip is considered for travel time estimations.

- *Trip motive*
  The trip motive can be interpreted in several ways as well. This can be defined as the destination of the trip, meaning a trip to work has the motive work while the return trip has the motive return home. However, such a definition would mean that almost half of the trips would have the motive return home, while for the determination of travel time values this is not very useful. Hence, the trip motive refers to the reason why the trip is made. Obviously a trip to work has the motive work, but the return trip also has this motive, because otherwise this trip would never have been made.
- *Transit line*
  This research focuses on the effects of two new transit lines. It is therefore important to define these for the survey, because for users this may not be as obvious as it is for transport planners. A transit line consists of all stations that are a stop of the new transit line. This includes stations of the line where transfers to other lines are available, but excludes all stations of other transit lines.

With the key terms defined, the survey content is set, in the form of a wish list. This wish list consists of three parts: required information for the estimation of indicators, information for data expansion and general information to describe the sample. For this research, the data is expanded based on the boarding station, because socio-economic characteristics are mostly influenced by the job and residential location. The items on the wish list for the sample description can also be used to extend the equity analysis if desirable. The wish list is shown in Table 5-3. Now, the most appropriate survey method is to be selected. Since this research focuses on surveying specific routes, on-board and intercept surveys are the most appropriate survey methods. The main difference between the two is that an intercept survey takes place in stations, while on-board surveys take place on-board public transport. The pilot survey showed that it was more difficult to find respondents using an intercept survey, because passengers are often in a hurry. Furthermore, the field visits during morning and afternoon peak showed that the Metro was often not too busy to conduct on-board surveys. Therefore, for the user survey an on-board survey is most appropriate. For the non-user surveys, on-board surveys are more difficult, because this is only applicable to public transport. Therefore, intercept surveys are used for the non-user surveys, focusing on passengers waiting to board public transport and vehicles waiting at traffic lights. In order to limit the number of uncompleted surveys, these surveys have to be particularly short.

Indicators	Wish list
Travel time savings, equity	Current travel time
	Previous travel time
	Trip purpose
	Income
Modal shift, air pollution, climate change	Previous transport mode
	Trip generation
Safety	Current safety perception
	Previous safety perception
Data expansion	Boarding station
Sample description	Age
	Income
	Education
	Sex
	Car ownership
	Alighting station
	Trip frequency

Table 5-3: Survey wish list.

The theoretical population of the sample consists of all transit line users and all non-users. All users are also part of the study population, because all of them can theoretically be reached by the survey. However, not all non-users can be reached, because intercept surveys can only be conducted at several locations. Furthermore, these surveys are only relevant for a limited number of non-users: those using corridors affected by the new transit line. Hence, only non-users on a parallel corridor are considered part of the study population, because for them the largest change in traffic volume and thus impacts are expected. More specifically, for the Metrobús line this concerns non-users on the same road, while for the Metro this concerns the major roads parallel to the Metro line. Respondent selection also influences results, because randomness is required to select a representative sample. If, for example, respondents are selected based on appearance (i.e. if they seem open to participate) then the representativeness of the sample is impaired. Therefore, selecting every n^{th} person in the Metro improves the representativeness of the sample. For the Metro an additional consideration is that in the first few wagons only women, children and elderly are allowed, which means that to obtain a representative sample at least one female surveyor is required.

Based on the information above, the surveys were constructed. These are based on the Metrobús survey to improve comparability. However, the surveys have been shortened to reduce the required time. After the surveys were constructed a pilot survey was conducted on the 11th of November. This pilot survey consisted of ten surveys for the Metro users and ten surveys for the non-users of the Metro. Based on this pilot survey, the formulation of some questions was slightly changed and the order of some questions was changed. This has resulted in the user survey for the Metro, which is shown in Appendix L. The pilot survey showed that the estimated time to complete one survey is between three and five minutes. The non-user survey for the Metro is shown in Appendix M. The non-user survey for the Metrobús is the same. The pilot survey showed that the time to complete one survey is less than three minutes. These surveys have been digitalized to a tablet format, to increase ease-of-use and the time required for the surveys.

5.3.3 SAMPLE SIZE

In section 3.6.2 the theory of calculating sample sizes was discussed. This section uses this theory to calculate the required sample size for the survey. Unfortunately, the standard deviation is required for this calculation, which is only known after the survey has been conducted. Richardson et al. (1995) suggest using comparable previous studies to estimate the standard deviation of the parameter in question. The main parameter of interest for the survey is travel time, but no literature on travel time variations in Mexico was found. OECD (2011a) did study income inequalities in Mexico and this provides some information on the standard deviation, as the squared coefficient of variation for income is stated (2.827). The coefficient of variation CV expresses the relation between the standard deviation σ and mean value μ (Ortúzar and Willumsen, 1990), as is shown in Equation 5-1.

$$CV = \sigma / \mu \qquad \textbf{Equation 5-1}$$

With this information, the sample size is determined, which is shown here for the Metro corridor. First, the confidence level is set to 95%, which results in a corresponding z-value of 1.96 (i.e. $\mu \pm 1.96\sigma$ contains 95% of the normal probability distribution). In line with other transport sample size calculations the confidence limit is set at 10%, implicating an interval of: $\mu \pm 0.1\mu$. Then, the standard error is calculated using Equation 5-2.

$$SE(\mu) = \frac{confidence\ limit}{z} = \frac{0.1\mu}{1.96} = 0.051\mu \qquad \textbf{Equation 5-2}$$

Next, the standard deviation is expressed in terms of the mean value and coefficient of variation, see Equation 5-3.

$$CV \cdot \mu = \sigma \rightarrow CV^2 \cdot \mu^2 = \sigma^2 \qquad \textbf{Equation 5-3}$$

Next, the sample size is calculated using Equation 5-4.

$$n' = \frac{\sigma^2}{\left(SE(\mu)\right)^2} = \frac{CV^2 \cdot \mu^2}{(0.051\mu)^2} = \frac{CV^2}{0.051^2} = \frac{2.827}{0.051^2} = 1{,}086 \qquad \textbf{Equation 5-4}$$

The total number of daily passengers is regarded as the population size. For the Metro corridor this equals an estimated 430,000 daily passengers. Correction for the population size results in the sample size shown in Equation 5-5.

$$n = \frac{n'}{1 + (n'/N)} = \frac{1{,}086}{1 + \frac{1{,}086}{430{,}000}} = 1{,}083 \qquad \textbf{Equation 5-5}$$

Hence, a survey size of 1,083 respondents is sufficient. Furthermore, the calculations show that correcting for population size is insignificant, as this declines the sample size only by three respondents (0.3%). Hence, the population size is high enough to disregard correction for it. Thus, a sample size of almost 1,100 is large enough. Decreasing the confidence limit to 5% would increase the required sample size to 4,301. This would significantly increase the sample size and is therefore not recommended.

Nonetheless, the sample size of 1,100 respondents is still high. This is mainly due to the high coefficient of variation for Mexican income, which may not be as high for travel times. Hence, literature on travel time variation in other contexts than Mexico was assessed. Tseng et al. (2005) conducted a meta-analysis of travel time valuation and found nine studies indicating coefficients of variation ranging between 0.131 and 0.576, with a mean value of 0.332. Compared to the squared coefficient of variation of 2.827 for income (i.e. CV = 1.681), these values are much lower. Using the same method, confidence level and confidence limit as above, this would require sample sizes between 7 and 128 respondents, which are significantly lower. For a confidence limit of 5% the maximum required sample size is 509. However, it can be expected that travel time variations in Mexico are higher, given the higher inequality. Thus, it is desirable to conduct more surveys, just to be on the safe side. Nonetheless, this number can be lower than the more than thousand based on income variations. Between 300 and 500 surveys for the Metro would allow a maximum CV of travel time of 0.781 and 1.30 respectively, still considerably higher than the values found in literature, but significantly lower than the value found for income variation.

Besides the user survey, non-user surveys are conducted. However, travel time benefits are expected to be much lower for non-users. Therefore, to accurately estimate effects, it was decided to conduct around 80% of the surveys among users and the remaining 20% among non-users. This means that at least 75 respondents are required for both non-user surveys.

5.4 INDICATOR CALCULATION METHODS

This section describes the methods used to calculate the indicators selected in section 5.2. As in that section, first the social indicators are addressed, followed by the environmental indicators and the economic indicators. Finally, the data expansion method is elaborated on. All the indicators were calculated using MatLab to ease the process of making changes.

5.4.1 SOCIAL INDICATORS

First the calculation method for the equity indicator is discussed. Next, the safety indicator calculation method is addressed.

5.4.1.1 EQUITY

The equity indicator concerns the distributional effects of the transport systems. Since travel time savings generally represent the majority of the benefits, travel time savings is the indicator along which equity effects are measured. However, this does not represent a situation before and after implementation. Therefore, the current and previous travel time are used. For this study, equity is measured vertically and with regard to income. This means that travel times are evaluated among income groups. In the evaluation assumptions it was already mentioned that egalitarianism is used to improve the incorporation of equity in the evaluation. This means that there is an improvement in equity if the socio-economically less fortunate profit more than the socio-economically more privileged. This means that the equity test aims at evaluating if the travel times decrease more for lower incomes than for higher incomes. For this comparison non-monetized travel times are most suitable, because irrespective of income, the available time in a day is equal for every person. An option to conduct the evaluation is to simply plot the relative travel time change (i.e. travel time savings as percentage) as a function of income. This shows if travel times decrease along with income. However, this does not quantitatively describe the change.

Wee and Geurs (2011) discuss several methods to more quantitatively calculate distributional effects, one of which is the Gini-index. This coefficient is often used to express inequalities in incomes. To do so, all incomes are ordered from low to high on the x-axis. On the y-axis the cumulative indicators are plotted. The resulting curve is called the Lorenz curve and usually has an exponential form. Besides the Lorenz curve, a line of a perfectly equal distribution (i.e. every person has same income) is plotted which is generally a line at a 45° angle (see Figure 5-1). The Gini-index is then calculated by dividing the surface area between the Lorenz curve and the equal distribution line by the surface area between the equal distribution line and the axes. Hence, the lower the Gini-index, the more equal the distribution.

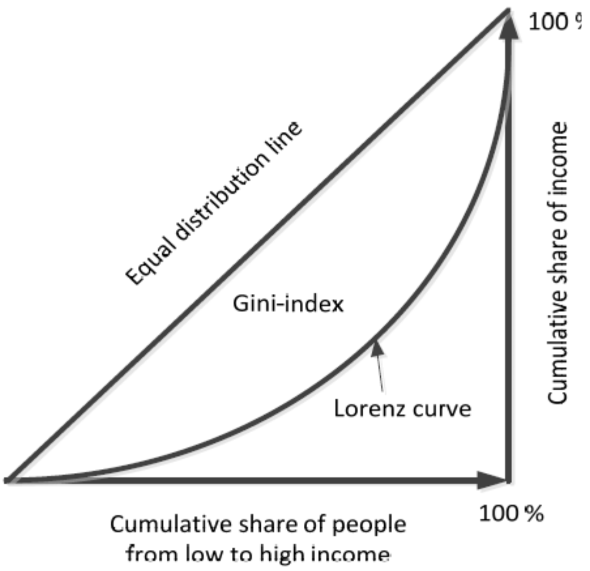

Figure 5-1: Gini-index illustration with Lorenz curve and equal distribution line (Wee and Geurs, 2011).

This principle can also be used to estimate the distribution of travel time over income. However, income is considered a utility and travel time a disutility. Hence, an increase in income is experienced positively while an increase in travel time is considered negatively. Therefore, the inverse of travel time is taken to overcome this problem. Next, the inverse previous travel time (in hours) is summed per income group. These income groups are then sorted from low to high. Next, the cumulative share of the number of trips and the cumulative share of inverse previous travel time are calculated. Similar to the example, these are then plotted; with on the x-axis the cumulative share of trips sorted from low to high income and on the y-axis the cumulative share of inverse previous travel times. This results in a Lorenz curve. In combination with an equal distribution line, this is used to calculate the Gini-index of previous travel times. The same is done for the current user travel times.

It is important to note that this is not an exact reproduction of the income Gini-index, because the indicator on the x-axis is not the same as the indicator on the y-axis. As a result, the Gini-index may in fact have a negative value, in case the low incomes experience lower travel times than the high incomes. Nonetheless, this still means that the lower the Gini-index, the more equality. In order to compare the before and after situation, the Gini-index of the current travel times is compared with Gini-index of the previous travel times. This way, the relative change in equity is calculated. Since no exact incomes, but only income groups, of respondents are known it assumed that travel times are evenly distributed over the income group. This means that if the first income group represents 20% of all trips and 25% of all inverse travel times, then a straight line between the origin of the axes and the point with an x-value of 20% and y-value of 25% is drawn. As a result, the Lorenz curve will not be a smooth line. Thus, a less accurate approximation of the surface areas is made.

The surface area of the Gini-index is the surface area between the equal distribution line and the Lorenz curve. The surface area of the Lorenz curve can be calculated by multiplying the average cumulative inverse travel times for each income group with the average cumulative number of travelers in the same income group. A summation of all these surface areas gives the surface area of the Lorenz curve. Dividing the surface area of the Gini-index by the surface area of the equal distribution line gives the Gini-index. This is written down mathematically in Equation 5-6 and Equation 5-7.

$$
\begin{aligned}
A\,(Gini) = A(eq.) - A(Lorenz) &= \frac{1}{2} * 1 * 1 - \sum_{i=1}^{n_i} \frac{1}{2} \cdot (ITT_i + ITT_{i-1}) \cdot (P_i - P_{i-1}) \\
&= 0.5 - \sum_{i=1}^{n_i} \frac{1}{2} \cdot (ITT_i + ITT_{i-1}) \cdot (P_i - P_{i-1})
\end{aligned}
$$

Equation 5-6

$$
\text{Gini} = \frac{A(Gini)}{A(eq.)}
$$

Equation 5-7

Where:

Gini	Gini-index
A(Gini)	Surface area Gini-index
A(eq.)	Surface area equal distribution line
A(Lorenz)	Surface area Lorenz curve
n_i	Total number of *i*
i	Income group *i*
ITT	Cumulative inverse travel times
P	Cumulative number of travelers

5.4.1.2 SAFETY

This research measures safety in terms of the users' and the non-users' safety perception of the system. In the survey, respondents are asked about their current perception of safety from accidents on a scale from one to ten. Additionally, respondents are asked the same question about their safety perception before the introduction of the system. This provides insights in the change in safety perception as a result of the implementation of the new transit line. The relative change in safety perception is used as the indicator for safety. For example, if the previous average safety perception was seven and this has increased to eight, this equals a change of 14.3%.

An issue with the survey conducted for the Metrobús users is that this only provides insights in the current safety perception and not the previous safety perception. However, before the Metrobús was implemented, the users were using the other transport modes available in the same corridor. Hence, they were part of the current non-users of the Metrobús. Therefore, for this research the assumption is made that the previous safety perception of Metrobús users is the same as the previous safety perception of current non-users.

5.4.2 ENVIRONMENTAL INDICATORS

Three environmental indicators are used in this evaluation framework. First, the air pollution and climate change indicators are discussed simultaneously, because these use a comparable method. Subsequently, the modal shift indicator is explained.

5.4.2.1 AIR POLLUTION AND CLIMATE CHANGE

Air pollution can be measured with many different indicators, as many different pollutants are emitted due to transport. The literature review showed that the two pollutants to which transport contributes the most are carbon monoxide and nitrogen oxides. Hence, these two pollutants are used to measure the effect the two transit projects have on air pollution. Furthermore, the emissions of PM_{10} are included, because Litman (2011) shows that this pollutant has the highest societal cost per emitted gram. For the climate change indicator, CO_2 emissions are chosen as emission, because these are by far the largest transport-based climate change contributor.

In order to determine the change in air pollution and climate change, the before and after situation are compared. Litman (2011) proposes using traffic volumes per transport mode and calculating total emissions by using emission factors per transport mode. Normally, emission factors are an amount of emissions per vehicle or passenger kilometer travelled. However, the surveys do not provide insights in the trip distance, because this requires difficult computations. Therefore, the assumption is made that the trips in the zone influence are similar as the trips within Mexico City. Hence, an emission factor per trip per transport mode is used (in grams of pollutant per trip). SMA-GDF (2010a) and SMA-GDF (2010b) provide information on the emission factors per transport mode and per model year, as well as total vehicle kilometers travelled. Based on this, average emission factors per transport mode are calculated for an 'average vehicle'. Furthermore, the OD survey has been used to determine the emission factors per trip per transport mode (Ciudad de México, 2007). The results of this are shown in Table 5-4. It is important to note that this only includes mobile emissions, and not the point emissions resulting from the electricity production for modes such as trolleybus and Metro.

Transport mode	Emission factor (g/km)				Trip emission factor (g/trip)			
	PM_{10}	CO	NO_x	CO_2	PM_{10}	CO	NO_x	CO_2
Walking	0	0	0	0	0	0	0	0
Bicycle	0	0	0	0	0	0	0	0
Motorcycle	0.023	28.38	0.7	17.66	0.292	359.70	8.87	223.78
Car	0.016	13.16	1.25	224.48	0.203	166.79	15.84	2,845.14
Taxi	0.015	18	2.16	194.08	0.222	265.85	31.90	2,866.38
RTP	0.226	21.68	15.73	784.38	0.135	12.92	9.37	467.40
Combi/Micro/Autobús	0.146	56.02	10.39	583.18	0.087	33.38	6.19	347.51
Trolley bus	0	0	0	0	0	0	0	0
Metro	0	0	0	0	0	0	0	0
Metrobús	0.261	12.64	6.99	2,076.00	0.029	1.39	0.77	228.15

Table 5-4: Emission factors per transport mode and emission.

With these emission factors, the current and previous emissions can be approximated. It is important to note that the scrapping of some forms of public transport and the construction of others is incorporated in the emission factors per trip. Hence, the additional emissions due to the transit line implementation and the reduced emissions due to the scrapping of lower-capacity public transport are not calculated separately, but are incorporated in the change in number of trips. The total emissions are calculated using Equation 5-8.

$$Emissions = \sum_{m=1}^{n_m} e_m \cdot V_m \qquad \textbf{Equation 5-8}$$

Where:

m	Transport mode m
n_m	Total number of m
e	Trip emission factor
V	Trip volume

Next, the relative change of each pollutant is calculated. For the climate change indicator, this is already sufficient because the indicator consists of only one emission. For the air quality indicator it is required to combine the change of all three pollutants. All pollutants are considered equally important, so an average of the change in the three pollutants is used.

5.4.2.2 MODAL SHIFT

The modal shift concerns the previous transport mode of passengers. Hence, this indicator consists of an overview of the percentages of which transport mode passengers used before the implementation of the new transit line. However, for this indicator it is most interesting to note the shift from private to public modes, because this provides the largest environmental benefit. Also, this means that travelers are willing to shift from a mode which is generally concerned more comfortable. The two modal shifts that are of main interest are the car and taxi. Hence, to quantify this indicator, the summed percentage of travelers shifting from car and taxi to the new transit line is considered.

5.4.3 ECONOMIC INDICATORS

Four economic indicators are included in the evaluation framework. Of these, the travel time savings indicator is the most complicated and is discussed first. After that, the construction costs, operating and maintenance costs and revenues are addressed. Finally, the calculation methods used to calculate future values of the economic indicators is addressed, because this extrapolation is required for economic aggregation.

5.4.3.1 TRAVEL TIME SAVINGS

Department for Transport (2014b) explains that for project appraisal two types of travelers exist: existing and substituted users. Existing users already use the existing road or transport system and substituted users shift after implementation. The associated user benefits are calculated using consumer surplus theory, which defines consumer surplus as the enjoyed benefits in excess of the perceived costs. Benefits are not equal for every traveler, because transport demand changes along with costs. Existing users enjoy the full benefits, because they experience the full decrease in travel time. Substituted users on average only enjoy half the benefits, because some already would have shifted with a slight travel time decrease, but some only shifted with the new travel time. This approximation principle is called the “rule of half”. In this ex-post evaluation a new mode is introduced in a corridor, but not on a city scale. Department for Transport (2014a) argues that a network extension is considered a new mode if the transport mode is extended to new OD pairs. Hence, the Metro and Metrobús line both are new modes, since they were previously unavailable in their service area. Department for Transport (2014a) also explains that for public transport, a new public mode is considered a submode of public transport. This implies that the Metro and Metrobús can be considered submodes of the broader public transport mode. As a result, all users that previously used public transport are considered existing travelers, whereas all other users are regarded substituted travelers. Hence, users shifting from other public transport modes are attributed the full benefits, while users shifting from other modes are attributed half the benefits, based on the rule of half. These benefits are calculated by subtracting the current travel time from the previous travel time. Furthermore, travel time savings are only applicable if the trip was made previously, because newly generated trips do not provide travel time savings. Hence, newly generated trips are excluded from the travel time savings calculation. For the non-users, all travelers are existing travelers and therefore everyone enjoys the full benefits.

Income group (Mex. pesos)	VOT (Mex. pesos/hour)	VOT (US$/hour)
$1 - $1,500	2.16	0.17
$1,501 - $4,500	8.65	0.66
$4,501 - $7,500	17.31	1.32
$7,501 - $15,000	34.52	2.48
$15,001 - $30,000	64.90	4.95
$30,001 - $45,000	108.17	8.25
More than $45,000	129.81	9.90
Average income ($17,095)	**49.31**	**3.76**

Table 5-5: Value of time per income group.

Travel time savings are monetized using the value of time, which is discussed in many studies. Odgaard et al. (2005) propose differentiation according to income and between work and non-work values. Work values relate to trips that are made while earning a salary, while non-work values relate to other trips, which include trip purposes such as commute, leisure and education. TRB (2002) agrees with this distinction, and mentions that some additional differentiation can be made according to trip length and waiting time, among others. Furthermore, leisure trips may have a higher VOT than commute trips. Using a VOT of 50% of the wage rate is suggested. Litman (2013) concurs with the work and non-work distinction, and proposes a VOT of 25% to 50% of the wage rate. Since the survey does not make a distinction between work and non-work trips, all trips are valued as non-work trips, because business trips generally only represent a minor fraction of all trips. Hence, the VOT is valued at 50% of travel time. Unique VOTs are used for each income group, but the equity VOT is also used, which represents a general VOT based on the average wage in the Federal District. This way, the utilitarian approach of CBA is avoided and high income groups are not made more important than low income groups. The VOT per income group is shown in Table 5-5. The monetized travel time savings for users are calculated using Equation 5-9 and Equation 5-11, while the monetized travel time savings for non-users are calculated using Equation 5-10 and Equation 5-12. The total travel time savings are the sum of the user and non-user travel time savings.

$$TTS_U = TTS_{ex.} + TTS_{subs.} = \sum_{i=1}^{n_i}\left(VOT_i \cdot \sum_{t=1}^{n_t}\left(CTT_{i,t,m_{PT}} - PTT_{i,t,m_{PT}}\right)\right) + 0.5 \cdot \sum_{i=1}^{n_i}\left(VOT_i \cdot \sum_{t=1}^{n_t}\left(CTT_{i,t,m_{private}} - PTT_{i,t,m_{private}}\right)\right)$$

Equation 5-9

$$TTS_{NU} = \sum_{i=1}^{n_i}\left(VOT_i \cdot \sum_{t=1}^{n_t}\left(CTT_{i,t} - PTT_{i,t}\right)\right)$$

Equation 5-10

$$TTS_{eq,U} = VOT_{eq} \cdot \sum_{t=1}^{n_t}\left(CTT_{t,m_{PT}} - PTT_{t,m_{PT}}\right) + 0.5 \cdot VOT_{eq} \cdot \sum_{t=1}^{n_t}\left(CTT_{t,m_{private}} - PTT_{t,m_{private}}\right)$$

Equation 5-11

$$TTS_{eq,NU} = VOT_{eq} \cdot \sum_{t=1}^{n_t} (CTT_t - PTT_t)$$ **Equation 5-12**

Where:

TTS	Monetized travel time savings
TTS_{eq}	Equitably monetized travel time savings
U	Users
NU	Non-users
i	Income group i
n_i	Total number of i
m	Transport mode (PT or private)
VOT	Value of time
VOT_{eq}	Equity value of time
t	Trip number t
n_t	Total number of t
CTT	Current travel time
PTT	Previous travel time

5.4.3.2 CONSTRUCTION COSTS

The construction costs do not require much calculation, since the total construction costs of the entire transit line are available. However, in order to make a useful comparison between the two projects, it is required to calculate the construction costs per kilometer. Hence, total construction costs are divided by the length of the corridor.

5.4.3.3 OPERATING AND MAINTENANCE COSTS

The operating and maintenance costs are determined differently for both transit lines. For the Metrobús, the cost calculation is divided into maintenance costs and operating costs. The latter are based on the price per kilometer paid to operators and the total vehicle kilometers travelled in a year. The Metrobús interview showed that for all lines operating costs are more or less equal, while Nava (2013) indicates the payment is 22.10 Mexican pesos per vehicle kilometer travelled. Metrobús (2013a) presents the vehicle kilometers travelled per month per line. For the Metro a study conducted by CTS Embarq on operating and maintenance costs of the Metro is used. The average operating and maintenance costs of all lines is extrapolated to line twelve only, using average costs per kilometer and adjusting for inflation. Operating and maintenance costs are calculated per year, because these are annual costs. The total annual operating and maintenance costs are divided by the corridor length to compare the two transit lines.

5.4.3.4 REVENUES

The revenues of the transit line are easily calculated based on the daily number of travelers and the ticket fare (three pesos for Metro, six pesos for Metrobús). However, passenger numbers are lower during weekends than on working days. SOBSE (2011) uses an annual equivalent of 292 working days. Another factor to take into account is that only additional revenues are collected if a modal shift from another mode is made. If a passenger already used the same system, then no additional revenues are collected, because a flat fare is paid for the use of the entire Metro or Metrobús system. Furthermore, some passengers do not pay a fare, because they are children, handicapped or elderly (over seventy years). For Metro line twelve, this constitutes to 9.57% of passengers (STC, 2013a) and for Metrobús line four this is estimated at 11.5%. The revenues are calculated using Equation 5-13. For Metrobús, the fare is dependent on boarding station, as the fare from the airport is higher. Therefore, a higher fare is applied for those passengers boarding at one of the two airport stations. In order to allow for a comparison between the two corridors, these revenues are divided by the corridor length, based on the assumption that revenues increase along with corridor length (and hence the surface area of the zone of influence).

$$R = P \cdot r \cdot WD_{eq} \cdot (1 - g) \cdot f$$ **Equation 5-13**

Where:

R	Annual revenues
P	Number of daily passengers
r	Fraction of new passengers
WD_{eq}	Number of working day equivalents per year
g	Fraction of passengers not paying fare
f	Ticket fare

5.4.3.5 FUTURE VALUES

The values of the economic indicators are evaluated over a period of fifteen years, as was discussed in section 5.1.2. In order to compensate for the decrease in the value of money over time, a discount rate of 12% is used. For the monetized travel time savings it is expected that wages will increase annually. Therefore, the VOT also increases annually. In order to compensate for this effect, the monetized travel time savings are increased with a fixed rate per year. Department for Transport (2014b) suggests using a rate based on the expected increase in GDP, as wages generally increase along with GDP. SENER (2012) projects that GDP in Mexico will increase with 3.6% annually. Equation 5-14 describes how this is calculated for the travel time savings. For the other costs and benefits the GDP growth rate factor can be left out (or a value of one can be used).

$$TTTS = \sum_{a=1}^{n_a} TTS_a \cdot r^a \cdot d^a$$ **Equation 5-14**

Where:

$TTTS$	Total travel time savings over project horizon
a	Year of project horizon
n_a	Length of project horizon
TTS	Annual travel time savings
r	GDP growth rate (1.036)
d	Discount rate (0.88)

5.4.4 DATA EXPANSION

The survey data only represent a sample of the entire population. Hence, expansion factors for the users and non-users of both transit lines are required. In order to get representative results for the entire population, it is required to expand the collected data. Often, data expansion is based on known socio-economic variables of the target population (Richardson et al., 1995). Unfortunately, socio-economic characteristics are only available for the Federal District, and not for the target population of the two transit lines. Hence, a different way to expand the data is required. For the users, the boarding station is used. The number of passengers boarding per station is known, and this provides information on the household location or employment location (depending on the time of day). The former is a good way to estimate socio-economic characteristics of the passenger, because users living in the same neighborhood are expected to have relatively similar socio-economic characteristics. Passengers employed in the same area also have similarity in their socio-economic characteristics, although less clearly than the household location. However, since the alternative is expanding the data only based on the total number of passengers, this is the best option for this study. Further distinction can be made based on time of boarding. However, the sample size is not large enough to maintain a representative sample for this.

For the Metrobús, CTS Embarq (2012) has studied the number of passengers boarding per station of line four. However, this study was conducted shortly after the line began operation and therefore the total number of passengers was only 31,882 on a working day. Metrobús (2013a) provides current passenger numbers, which were 1,471,732 for December 2012. This equals 59,344 passengers per working day. The assumption is made that the additional passengers are distributed proportionally to all stations. Based on the number of passengers and the number of surveys per station, the expansion factors are calculated, which is shown in Table A-1 in Appendix N.

For the Metro, STC (2013a) provides the number of passengers boarding at each station. However, this data only includes the passengers boarding if it is their first station. Hence, the total number of passengers is much larger, because many begin their trip at another line and transfer to line twelve. This concerns around 160,000 of the 430,000 daily passengers. Based on the daily passenger numbers, the number of passengers on a working day is calculated. Based on this and the number of surveys, the expansion factors are calculated; see Table A-2 in Appendix N. In order to maintain representativeness, subsequent stations are joined if the number of surveys of one of the stations is below ten.

For the non-users, a different method is required, because no information is available on trip origin and destination. Furthermore, effects on this population are expected to be smaller, so less distinction is necessary. Nonetheless, effects on car users are expected to be significantly different than on users of minibuses, for example. Therefore, the data is expanded according to transport mode. However, due to a limited number of respondents for some modes, modes are aggregated. In total, three categories are used, which are public road transport (microbuses, RTP, trolley bus), private road transport (motor, taxi, car) and public transit (Metro, LRT, Metrobús). These three categories of transport modes utilize similar infrastructure, so impacts are expected to be similar.

For the Metrobús corridor, the supply and demand study conducted by CETRAN (2009) provides information on the transport volumes within the zone of influence of line four before the line was implemented. Several elaborations were made to gain the required data for this research. From these volumes, the number of travelers that shifted mode is subtracted, because these no longer use their previous mode. This number of travelers is based on the user survey and their modal shift and yields the new traffic volume and modal split. Based on this data and the number of surveys conducted, the expansion factors are calculated, which is shown in Table A-3 in Appendix N. The number of trips by private modes is small compared to the trips by public transport, but this is because the line traverses the historic city center, which has many small, one-way streets that are inconvenient to navigate by private mode.

For the non-users of Metro line twelve, the ex-ante appraisal of Spectron Desarrollo (2009) is used to estimate the number of trips before the implementation of the Metro corridor. Several adjustments were made to gain useful data. Furthermore, the Metro non-users have been defined as the travelers on the routes parallel to the Metro line. This comprises the following streets: Av. Tláhuac, Eje 3 Oriente, Eje 8 Sur Ermita, Eje 8 Sur Popocatepetl and Eje 7 Sur Felix Cuevas. Again, the current number of trips is determined using the modals shift based on the Metro user survey. The expansion factor per mode is determined with the current number of trips and number of surveys per mode. The expansion factor per transport mode is shown in Table A-4 in Appendix N.

5.5 INDICATOR AGGREGATION

This section discusses how the indicators are aggregated. First the flag model is explained. This is the aggregation method that is applied for this study. Secondly, the critical threshold values that are part of this aggregation method are elaborated on.

5.5.1 THE FLAG MODEL

As was already mentioned in the evaluation framework, the flag model is used to aggregate the indicators. Nijkamp and Ouwersloot (1997) introduce the flag model as a method to evaluate social, economic and environmental indicators. Hence, this model is particularly suitable for this framework. The social, economic and environmental indicators are composite indicators, consisting of one or more basic indicators. For this research, the composite social indicator consists of two basic indicators, the composite environmental indicator of three basic indicators and the composite economic indicator of four basic indicators. The flag model attributes a colored flag to each basic indicator, based on critical threshold values. For cost indicators, a value below the CTV is desirable, while for benefit indicators a value above a certain CTV is desirable. The flag model uses three (green, orange, red) or four (black) flag colors to assign to each indicator. For this study, four flag colors are used. Often, the green flag refers to ‘sustainable’, the orange flag to ‘ambiguous sustainability’, the red flag to ‘unsustainable’ and the black flag to ‘very unsustainable’. CTVs can be based on expert consultation or a literature study. Since expert consultation often leads to ambiguity in the CTVs, a literature study is used for this research. The resulting CTVs per indicator are elaborated on in section 5.5.2.

Once a flag for each indicator is determined, the indicators are evaluated. Nijkamp and Ouwersloot (1997) suggest three ways to do so: qualitative, quantitative and hybrid evaluation. Qualitative evaluation is simplest and simply counts the number of flags. For quantitative evaluation, the values are standardized using the CTVs. The outcomes are rescaled on a scale where the value -1 corresponds to the CTV_{min} and 1 is associated with CTV_{max}. Finally, the hybrid evaluation is computed using a combination of the qualitative and quantitative evaluation. To do so, the standardized outcomes are plotted on an interval, which is divided into sub-intervals indicating the corresponding flag color. To compare the two transit lines, on the x-axis the standardized outcomes of the Metrobús line are plotted, while on the y-axis the outcomes of the Metro line are plotted. A 45° equal division line indicates if an indicator performs better for the Metro line or the Metrobús line. If the indicator is below the line, the Metrobús performs better, while an indicator above the line means the Metro performs better.

In order to draw more solid conclusions on the social, environmental and economic performance of the transit line, the basic indicators are aggregated to the composite indicator. The value of the composite indicator is calculated based on the standardized value of its basic indicators. No weighting is applied for this, as all indicators are considered equally important. Hence, the average of the standardized values of the basic indicators is calculated to determine the standardized value of the composite indicator. This standardized value is then used to attribute a flag color to the composite indicator. This way, each composite indicator can be included in the plot to compare the projects. Finally, the three composite indicators are aggregated to determine an overall standardized value for the project. However, this outcome is not the most important of the study, because the performance on social, environmental and economic indicators should be sustainable and one indicator compensating the other is not considered sustainable.

The economic indicators are also aggregated in a different way, using the net present value, which is done by summing all discounted economic costs and benefits for the project horizon. This gives an indication if the project is economically profitable. Furthermore, the B/C ratio is used. This expresses the ratio between the discounted benefits and costs and thereby gives an indication of the economic efficiency of the project.

5.5.2 CRITICAL THRESHOLD VALUES

The critical threshold values are of major importance for the results of the study, as these indicate the sustainability of an indicator. In order to establish the values of the CTVs, a literature study is used. Many papers and reports on the effects of transport projects have been studied. Unfortunately, not all impacts are regularly included in other studies. This is partly the result of the indicator selection, because some indicators were selected because of their uniqueness in transport evaluation (especially equity). An overview of the effects that are found in literature is shown in Table A-5 in Appendix O. This literature review consists of sixteen BRT studies, six MRT studies, one analysis focusing on a new tram line, one on increasing public transport speed and one study on infrastructure improvement. Many of these studies are ex-ante appraisal and therefore do not portray actual effects, but estimations. Nonetheless, these give an indication of the magnitude of the effects. Some studies also focus on one particular effect and compare various projects. The findings are summarized in Table 5-6 using the minimum, maximum and average values, as well as the standard deviation and the number of studies on which the findings are based.

Indicator	Minimum	Maximum	Average	Standard deviation	Number of studies
Accidents	-60.0%	-1.5%	-34.9%	19.9%	7
Equity	-1.8%	23.1%	8.6%	12.9%	3
Air pollution	-71.4%	-12.0%	-39.2%	27.1%	4
Climate change (ton CO2/year)	-83.0%	-2.3%	-42.0%	24.3%	15
Modal shift from car	4.4%	18.0%	10.9%	4.6%	9
Travel time	-42.0%	-1.7%	-26.4%	10.9%	16
Construction costs (US$/km)	$669,643	$329,900,000	$46,236,052	$59,046,263	62
Operating and maintenance costs (US$/year/km)	$911,892	$1,702,779	$1,305,676	$318,077	5
Operating revenues (US$/year/km)	$129,747	$2,575,000	$1,099,501	$917,247	10
Construction costs BRT (US$/km)	$669,643	$23,748,095	$6,724,998	$5,861,768	30
Construction costs MRT (US$/km)	$16,100,000	$329,900,000	$87,523,801	$60,136,061	31

Table 5-6: Range of indicator values found in literature.

The table shows that for equity the effects range from a slight deterioration of 1.8% to a significant improvement of 23.1%. The average of 8.6% is based on only three studies, since equity is often not included in transport effect studies. However, this shows that a slight improvement in equity is expected. The other social indicator refers to safety and is most often measured in the number of accidents. Seven studies included relative changes of accidents, although more include the monetized effect of accidents. Results range between a small decrease of 1.5% in the number of accidents and a significant reduction of 71.9%. The average reduction in accidents of 37.9% shows that a significant safety improvement is expected.

Similar to accidents, the environmental indicators are often expressed in monetary terms and therefore relative change is only found in a limited number of studies. The effects on climate change show a large range, with a CO_2 emission reduction ranging between 2.3% and 83%, averaging at 42.0%. For air pollution, emission reductions are between 12.0% and 75.1%. The average air pollution decrease is 45.2%. The modal shift ranges from 4.4% to 18.0%, averaging at 10.9%, which indicates that a significant number of public transport users previously used a private mode (car or taxi).

The construction costs of BRT and MRT infrastructure has been expressed in US$ per kilometer, because otherwise comparison would be impossible. These findings are based on studies focusing on effects of a single BRT or MRT system and on three studies specifically discussing the construction costs of BRT and MRT systems and therefore incorporating many systems at once. This explains the high number of studies. Construction costs range from US$ 0.7 million to US$ 329.9 million per kilometer. Construction costs average at US$ 46.2 million. However, splitting the construction costs for BRT and MRT provides some insights in the differences in the construction costs. BRT construction costs are significantly lower than MRT construction costs, averaging US$ 6.7 million per kilometer and US$ 87.5 million per kilometer, respectively. This difference was already mentioned in the literature review, but these numbers stress this even further. Interestingly, the study by Flyvbjerg et al. (2008) shows that MRT construction costs are higher in the US than in Europe, Asia and Latin America. Fewer studies incorporate system operating and maintenance costs and operating revenues. Some studies express these in terms of costs or revenue per vehicle kilometer travelled, but most use the total costs per year. These have been converted to costs or revenues per kilometer. Operating costs average around US$ 1.3 million per kilometer while revenues are US$ 1.1 million per kilometer on average. All studies that incorporated the relative change in travel times found a travel time reduction. However, the magnitude differs significantly, ranging from 1.7% to 42.0% and average around 26.4%. Thus, a significant reduction in travel time is expected due to the implementation of a new public transport system.

The values that are presented in Table 5-6 are used to set CTVs. For this purpose, the assumption is made that the values are normally distributed. Furthermore, the CTVs are chosen in such a way that, assuming a normal distribution, all flags have an equal likelihood (25%) of occurring. This means that the CTV is set at the average, the CTV_{min} at the average minus 0.674 standard deviations and the CTV_{max} at the average plus 0.674 standard deviations. This results in the values shown in Table 5-7. A special note has to be made for the accident and travel time savings indicators, for which the signs have been inverted, because the effects in the literature study concern the number of accidents and total travel time, while this research focuses on the safety perception and travel time savings (for which a higher value is better). The CTVs in Table 5-7 are used to assign flags to the indicator values, displayed in Table 5-8. In the table, *X* represents the value of the indicator found in this study. Since these flags are based on values found in literature, the colors do not represent the same meaning as the literature prescribes. For example, a safety improvement of 20% would be described as ‘very unsustainable’, but still represents a significant improvement. Therefore, black flags refer to ‘low performance’, red flags to ‘low to medium performance’, orange flags to ‘medium to high performance’ and green flags to ‘high performance’.

In order to avoid a very high or very low standardized value of an indicator dominating the aggregated results, for this study a minimum standardized value of -2 and a maximum standardized value of 2 is used. This is done, because otherwise a single indicator could have a value of plus six, thereby compensating low scores of several other indicators. This way, the value of one indicator could transform results from a very negative score to a slightly positive score, for example. Hence, the standardized score is set at -2 if it is below -2 or 2 if it exceeds 2. This way, the standardized value of a single basic indicator cannot be overrepresented in the composite indicators.

Indicator	CTV_{min}	CTV	CTV_{max}
Safety	21.5%	34.9%	48.3%
Equity	-0.1%	8.6%	17.3%
Air pollution	-57.5%	-39.2%	-20.9%
Climate change	-58.4%	-42.0%	-25.6%
Modal shift	7.8%	10.9%	14.0%
Travel time savings	19.8%	26.4%	33.8%
Construction costs (per km)	$6,409,938	$46,236,052	$86,062,166
Operating costs (per year per km)	$1,091,136	$1,305,676	$1,520,215
Revenues (per year per km)	$480,827	$1,099,501	$1,718,176

Table 5-7: CTV_{min}, CTV and CTV_{max} per indicator.

Safety	X<21.5%	21.5%<X<34.9%	34.9%<X<48.3%	X>48.3%
Equity	X<-0.1%	-0.1%<X<8.6%	8.6%<X<17.3%	X>17.3%
Air pollution	X<-57.5%	-57.5%<X<-39.2%	-39.2%<X<-20.9%	X>-20.9%
Climate change	X<-58.4%	-58.4%<X<-42.0%	-42.0%<X<-25.6%	X>-25.6%
Modal shift	X<7.8%	7.8%<X<10.9%	10.9%<X<14.0%	X>14.0%
Travel time savings	X<19.8%	19.8%<X<26.4%	26.4%<X<33.8%	X>33.8%
Construction costs (per km)	X<$6,409,938	$6,409,938<X<$46,236,052	$46,236,052<X<$86,062,166	X>$86,062,166
Operating costs (per year per km)	X<$1,091,136	$1,091,146<X<$1,305,676	$1,305,676<X<$1,520,215	X>$1,520,215
Revenues (per year per km)	X<$$480,827	$480,827<X<$1,099,501	$1,099,501<X<$1,718,176	X>$1,718,176

Table 5-8: Flag color per indicator value.

5.6 SENSITIVITY ANALYSIS

This section discusses the sensitivity analysis of several assumptions that are made for the calculation of the indicators. The sensitivity analysis changes several of the input parameters to evaluate the effect this has on the outcomes of the study. This sensitivity analysis includes variations in the value of time, emission factors and the indicator along which equity is measured. Furthermore, the sensitivity analysis also applies the flag model for two specific situations. First of all, the flag model is applied to only the direct (user) benefits. Secondly, the hypothetical situation in which a full BRT line is implemented for Metrobús line four is analyzed.

In order to determine the travel time savings, an equity value of time based on the average income in the Federal District is used. This value of time is based on 50% of the hourly wage. However, literature values of the value of time vary significantly. Hence, uncertainty exists if the chosen value of time is in fact correct. Therefore, the sensitivity analysis varies the value of time. This variation is done in two ways. First of all, an income-dependent value of time is applied, in which the value of time is varied per income group. Also, in accordance with the standard evaluation, the equity value of time based on the average monthly income (17,095 Mexican pesos) is used. Additionally, an equity VOT based on the median monthly income (12,028 Mexican pesos (INEGI, 2012)) is used, because this decreases the influence of the highest income groups on the VOT. Secondly, the percentage of income on which the VOT is based is varied. The value of time is set at 25%, 50% and 100% of the income. Hence, a total of nine scenarios are analyzed for the sensitivity of the value of time. The economic aggregation is used as indicator of the sensitivity. Therefore, the NPV and B/C ratio are determined for each scenario, indicating the profitability and economic efficiency of both lines.

The emission factors are the most important determinant of the air pollution and climate change indicators. In order to analyze the effect of these emission factors, three scenarios have been constructed. The first scenario includes the point emissions resulting from the production of electricity for the Metro. For these emissions, the assumption is made that the emission factor for the Metro is equal to the emission factor for Metrobús. The second scenario assumes that the efficiency of public transport reduces due to the implementation of both lines. Hence, the average occupancy per vehicle is lower, increasing the average emissions per trip. Therefore, the emission factors for microbuses, autobuses, micros and RTP are doubled. The third scenario assumes technological advancement in private vehicles, for example due to higher fuel taxes or stronger legislation. Therefore, the emission factors for cars and taxis are reduced by 50%. These scenarios are somewhat exaggerated, but nevertheless serve well to illustrate the effects of emission factors on the outcomes. The effects of the scenarios are measured using the relative change and the annual emission reductions in air pollution and climate change.

The equity indicator is based on the distribution of travel time savings along income group. However, effects may be different if other social characteristics are used. For these characteristics it is important that they are ordinal. Therefore, the equity indicator is also calculated based on the distribution of travel time savings along age and level of education. Both of these provide insight in the influence of the social characteristic on the equity indicator. Additionally, the Gini-index is calculated based on the distribution of travel times. In this case, the same methodology is applied as for the income Gini-index. The x-axis represents the cumulative share of trips, ordered by inverted travel time. The y-axis characterizes the cumulative share of inverted travel times. Hence, this shows the distribution of travel times, regardless of any social characteristic. The change in the Gini-index represents the change in the equality of the distribution of travel times.

The sensitivity of the flag model is analyzed in two ways. First of all, only the direct effects are taken into account. This means that only the user benefits are incorporated, which is what is done in most of the literature used to determine the CTVs. This is only applicable for the travel time savings, equity and safety indicators, because the others already only take into account direct effects. Secondly, the effects are estimated if a full BRT line was implemented for the Metrobús corridor. In order to do this, it is assumed that a similar capacity as the first Metrobús line was acquired. Therefore all expansion factors are increased by a factor that is based on the ratio between the number of monthly passengers of line one and the number of monthly passengers for line four, corrected for system length. Data from Metrobús (2013a) show that this factor is approximately six. However, it has to be noted that construction costs and operating and maintenance costs were not adjusted, because this requires too detailed investigation for this sensitivity analysis.

CHAPTER 6. RESULTS

This chapter discusses the results of the ex-post evaluation. These results are achieved by applying the methodology discussed in the previous chapter. This chapter first describes the survey samples that were obtained through the survey conduction. After that, the results are presented for each individual indicator. First, the results for the social indicators are given, followed by the results for the environmental indicators and the economic indicators. Consecutively, the indicators are aggregated. Subsequently, the results of the sensitivity analysis are presented. Subsequently, the main findings of the interviews are displayed. Finally, based on these results some conclusions are drawn.

6.1 SAMPLE DESCRIPTION

The non-user surveys were conducted on Tuesday the 3rd of December 2013 and the user survey was conducted on Monday the 16th and Tuesday the 17th of December 2013. Two surveyors (one male, one female) were hired to conduct the surveys. The user surveys were conducted on-board, so the time burden for respondents was limited. The non-user surveys were conducted at public transport stops and parking zones to include different modes and increase the response rate. Respondents were randomly selected by choosing every fifth person in the Metro or non-user population. However, some bias was caused by people getting off the Metro quickly or non-users being in a hurry and therefore unwilling to participate. The Metro user sample size is 373, compared to a sample size of 369 for the Metrobús sample size. Hence, the user sample sizes are within the sample size range calculated in section 5.3.3. The non-user sample sizes are 104 for Metrobús and 78 for Metro. Hence, the Metro non-user sample size is slightly above the non-user sample size minimum, while the Metrobús non-user sample size is well above this minimum.

Table 6-1 describes the survey user and non-users samples of the Metro and Metrobús and also provides information on the Federal District where possible. The table describes the survey sample, and not the entire population. Hence, no expansion factors are applied to the respondents. The table shows that the average age for all survey samples is more or less equal. All samples show a more or less equal share of male and female respondents, except for the Metro user sample, which has more males. The level of education is higher for both Metro samples than the Metrobús samples, particularly due to the higher fraction of Bachelor degrees. Compared to the average of the Federal District, all survey samples portray a higher level of education. This may be caused by the higher level of employment and lower levels of students and housewives than the Federal District's average. This difference was expected, because employees tend to travel more than housewives, for example. The sample description shows that for all samples the unemployment rate is low. Meanwhile, the majority is self-employed or working in the public or private sector. Interestingly, self-employment is much higher among the Metrobús samples than the Metro samples. Furthermore, employment is higher among Metro users than Metro non-users, while for the Metrobús the reverse is true.

In terms of income groups significant differences exist as well. For the Metrobús, a clear difference exists in average monthly household income between the two surveys, which is more than twice as high for the user sample. Meanwhile, for the Metro the non-user sample is significantly higher than the user sample. However, for all samples the average income is less than half the average of the Federal District. This is underscored by the number of respondents with an income below 7,500 Mexican pesos, which represents the vast majority for all samples, while this is only 25% within the Federal District (INEGI, 2012). The Metrobús samples mainly differ in the second and fourth income group, the former of which is much larger for the non-user sample and the latter for the user sample. The main difference in the Metro's income groups is caused by the lowest income group, which represents a much larger fraction of the user than the non-user sample.

Trip frequencies between the two samples are comparable, since the majority of trips is made daily. However, a larger fraction of Metrobús trips is made regularly, while the Metro sample more frequently makes daily trips. The majority of the trips is made for work purposes, except for the Metro non-user sample. This sample has particularly more trips that are made for medical purposes and for visiting family or friends. The number of transfers from other lines is much larger for the Metro user sample than the Metrobús user sample. This is most likely caused by the lack of station integration for the Metrobús line. Finally, car ownership of both samples is considerable, since this indicates that a significant fraction of the users has the option to use a car, but chooses to use mass transit instead. However, compared to car ownership of the Federal District, this fraction is small.

	Characteristic	Metrobús user sample	Metrobús non-user sample	Metro user sample	Metro non-user sample	Federal District
	Age (years)	35	39	35	36	-
	Male (%)	45.3%	51.9%	62.5%	51.3%	-
	Car ownership (%)	22.2%	-	26.5%	-	52.2%[1]
	Transfer from other line	0.0%	-	23.3%	-	-
Education	No study	0.0%	3.8%	0.3%	0.0%	6.4%[2]
	Primary school	7.0%	3.8%	8.0%	1.3%	18.5%[2]
	Secondary school	35.2%	26.0%	19.3%	11.5%	33.5%[2]
	College	38.2%	51.9%	41.3%	43.6%	
	Bachelor	18.2%	13.5%	30.0%	39.7%	41.5%[2]
	Master	1.4%	1.0%	1.1%	3.8%	
Employment	Unemployed	1.4%	1.0%	0.8%	0.0%	3.6%[2]
	Student	11.7%	6.7%	12.3%	20.5%	13.3%[2]
	Housewife	14.4%	11.5%	7.5%	12.8%	18.9%[2]
	Retired	1.6%	1.0%	1.3%	3.8%	5.6%[2]
	Public sector	10.6%	10.6%	12.8%	11.5%	43.0%[2]
	Private sector	30.4%	37.5%	45.7%	30.8%	
	Self-employed	30.1%	31.7%	19.5%	20.5%	11.1%[2]
Monthly income group (MEX$)	$0 - $1,500	16.3%	18.3%	20.6%	3.8%	-
	$1,501 - $4,500	25.7%	51.0%	46.0%	48.7%	-
	$4,501 - $7,500	23.3%	26.0%	23.3%	28.2%	-
	$7,501 - $15,000	22.2%	3.8%	8.6%	10.3%	-
	$15,001 - $30,000	8.1%	1.0%	1.3%	6.4%	-
	$30,001 - $45,000	4.3%	0.0%	0.3%	1.3%	-
	More than $45,000	0.0%	0.0%	0.0%	1.3%	-
	Average	$8,248 (US$ 629)	$3,873 (US$ 295)	$4,293 (US$ 327)	$6,837 (US$ 522)	17,095 (US$ 1,304)[3]
Trip frequency	Daily (5-7 trips/week)	54.2%	-	72.7%	-	-
	Regularly (2-4 trips/week)	35.2%	-	19.0%	-	-
	Occasionally (1-2 trips/month)	7.6%	-	7.0%	-	-
	Almost never (less than once/month)	3.0%	-	1.3%	-	-
Trip purpose	Work	55.3%	59.6%	61.2%	38.5%	-
	School	11.1%	3.8%	8.3%	12.8%	-
	Food	1.9%	0.0%	1.6%	5.1%	-
	Visiting family/friends	8.1%	2.9%	10.2%	11.5%	-
	Shopping	16.0%	23.1%	5.3%	7.7%	-
	Leisure	6.0%	9.6%	8.8%	5.1%	-
	Medical	1.4%	1.0%	4.5%	17.9%	-
	Other	0.3%	0.0%	0.0%	1.3%	-

Table 6-1: Sample description.

[1] INEGI (2013b)
[2] INEGI (2013a)
[3] INEGI (2012)

For the four surveys that were conducted, some descriptive statistics are presented in Table 6-2. This table provides insights in the minimum, mean, maximum and standard deviation of some of the questions of the survey. The overview only includes ordinal survey questions, because for other questions these statistics are not useful (e.g. the mean of the trip motive provides no useful insights). The statistics show that the results are probable. For example, the previous travel time is higher than the current travel time for all surveys. Also, the difference in user and non-user travel times is obvious. Such results were expected beforehand. However, it should be noted that the standard deviation is high, which suggests that great differences exist in respondents' travel times. For the safety perception results are also as expected, because safety improves, especially for users. Also for safety perception, significant variations exist among respondents.

		Current travel time (min.)	Previous travel time (min.)	Current safety perception	Previous safety perception	Income group
Metrobús users	Minimum	5	5	1	-	1
	Mean	28.84	48.67	9.08	-	2.93
	Maximum	120	230	10	-	6
	Standard deviation	21.30	35.32	0.85	-	1.36
Metrobús non-users	Minimum	10	10	2	2	1
	Mean	60.57	64.98	6.78	5.63	2.18
	Maximum	360	360	10	10	5
	Standard deviation	42.05	41.56	1.84	1.80	0.81
Metro users	Minimum	5	15	1	1	1
	Mean	66.91	96.92	7.34	4.72	2.25
	Maximum	300	360	10	10	6
	Standard deviation	37.23	49.28	1.85	2.40	0.94
Metro non-users	Minimum	2	2	1	1	1
	Mean	45.92	54.23	4.78	4.32	2.76
	Maximum	180	240	10	9	7
	Standard deviation	28.36	34.27	2.34	2.22	1.13

Table 6-2: Descriptive statistics of the Metrobús and Metro user and non-user samples.

6.2 SOCIAL INDICATORS

This section discusses the social indicators. First, the results for the Metro and Metrobús lines are presented for the equity indicator. Next, the same is done for the safety indicator.

6.2.1 EQUITY

The results for the equity indicator are shown in Table 6-3. For the Metrobús, the Gini-index of travel times according to income was 0.025 before implementation, while currently the Gini-index is 0.017. Hence, due to the implementation of the Metrobús line an equity improvement of 31.3% was experienced. This means that the distribution of travel times has become more equal. This improvement is mainly due to indirect equity improvements, since this improvement is 57.3%, compared to 18.2% for direct equity effects. Furthermore, travel times are divided more equally for users than non-users, given the lower Gini-index. The travel time savings, see section 6.4.1, also give an indication of which income groups enjoy the largest travel time savings. This shows that, proportionally, the two lowest income groups enjoy few travel time savings, because their share of the total number of trips (9.6% and 62.3%) is higher than their share in the travel time savings (4.4% and 50.8%). The same holds for the fourth income group. Meanwhile, the third, fifth and sixth income groups enjoy proportionally more travel time savings (19.9% of trips and 38.6% of travel time savings). This suggests that inequality in the travel time savings exists.

For the Metro, the Gini-index was 0.092 before the opening of line twelve. A slight decrease to 0.055 resulted from the implementation of the Metro line. This equals an equity improvement of 39.8%. Hence, the distribution of travel times has become more equal. This improvement is mainly a direct effect, for which a 50.8% improvement is found, compared to a 40.8% indirect improvement. Furthermore, the Gini-indices suggest that there is more equality in the travel time distribution for users than non-users. The travel time savings per income group show that for all income groups the trip share more or less equals the percentage of travel time savings. This explains why only a small absolute improvement in equity is experienced. The only significant difference exists for the lowest income group, which enjoys more travel time savings than the average, and the fifth income group, which enjoys less travel time savings than the average.

A comparison between the equity impacts of the Metrobús and Metro line shows that the equity benefits are larger for the Metro project. However, the magnitude of effects is more or less similar, since benefits are 39.8% for Metro compared to 31.3% for the Metrobús. Furthermore, the results show that the equality of travel times is higher for the Metrobús project than for the Metro project, since the Gini-index of the Metrobús is lower. Nonetheless, direct inequality is somewhat higher for Metrobús than for Metro, while indirect inequality is significantly higher for Metro than Metrobús.

	Metrobús			Metro		
	Direct	Indirect	Total	Direct	Indirect	Total
Previous Gini-index	-0.068	0.030	0.025	0.043	0.072	0.092
Current Gini-index	-0.083	0.013	0.017	0.021	0.043	0.055
Improvement	**18.2%**	**57.3%**	**31.3%**	**50.8%**	**40.8%**	**39.8%**

Table 6-3: Equity indicator.

6.2.2 SAFETY

The direct and indirect safety perceptions for Metrobús are shown in Table 6-4. Direct safety effects show a significant improvement of 59.8%. Hence, Metrobús line four has clearly improved the perception of safety. However, a smaller direct safety improvement of 19.4% is found. This shows that non-users do enjoy some safety improvement as a result of the implementation of the Metrobús line, but that this improvement is much smaller. As a result, the overall change in safety perception is 23.4%. Compared to the direct safety improvement this is small. This is the result of the much larger number of non-users than users.

Effects	Previous safety perception	Current safety perception	Change
Direct	5.67	9.06	59.8%
Indirect	5.67	6.78	19.4%
Total	**5.67**	**7.00**	**23.4%**

Table 6-4: Safety perception for Metrobús.

The direct and indirect safety perception for Metro is shown in Table 6-5. Both direct and indirect effects on safety perception are positive. However, the direct improvement is much larger at 55.7%, compared to an indirect safety impact of 10.5%. The total improvement in safety perception is 29.6%. Interestingly, previously both direct and indirect perception of safety was low, below a score of five. Currently, this still holds for the non-users, but for users the safety perception is relatively high with a score of more than seven.

Effects	Previous safety perception	Current safety perception	Change
Direct	4.67	7.28	55.7%
Indirect	4.28	4.73	10.5%
Total	**4.44**	**5.75**	**29.6%**

Table 6-5: Safety perception for Metro.

The safety impacts of Metro and Metrobús are very similar. The direct and indirect improvements are slightly higher for Metrobús, but the overall improvement is higher for Metro. This is the result of the fraction of total trips made by users is much higher for Metro than for Metrobús. In absolute terms, the previous safety perception was significantly (more than one point) higher for Metrobús than for Metro. Also the current safety perception is significantly higher for Metrobús than Metro, which shows that Metrobús users perceive safety to be higher than Metro users.

6.3 ENVIRONMENTAL INDICATORS

This section presents the results of the environmental indicators. First, the air pollution and climate change indicators are discussed simultaneously. Secondly, the modal shift indicator is addressed.

6.3.1 AIR POLLUTION AND CLIMATE CHANGE

The annual emissions of pollutants and GHGs for the Metrobús line are shown in Table 6-6. This shows that all pollutant emissions have decreased due to the implementation of the Metrobús, of which especially CO and NO_x emissions have decreased. PM_{10} emissions also decreased, but to a smaller extent. The average emission reduction of the three pollutants is 12.3%, which is the value used for the air pollution indicator. For climate change, a decrease in CO_2 emissions is also evident from the results. The table shows that transport emissions in the zone of influence have reduced by 4.9%.

	Air pollution			Climate change
	PM_{10} (ton/year)	CO (ton/year)	NO_x (ton/year)	CO_2 (ton/year)
Previous emissions	5.27	3,083	391.9	46,259
Current emissions	4.82	2,646	336.1	44,013
Change	**-8.5%**	**-14.2%**	**-14.2%**	**-4.9%**

Table 6-6: Air pollution and climate change indicators for Metrobús.

The current and previous annual emissions of pollutants and GHGs for the Metro line are shown in Table 6-7. All three pollutants show a significant decrease in annual emissions. This decrease is highest for PM_{10} at 31.1% and lowest for CO at 27.1%. The annual NO_x emissions decrease by 30.5%. This means that the air pollution indicator value is -29.6%, the average of the three pollutant emission changes. The climate change indicator has a slightly lower reduction of 22.8%.

	Air pollution			Climate change
	PM_{10} (ton/year)	CO (ton/year)	NO_x (ton/year)	CO_2 (ton/year)
Previous emissions	37.33	18,046	2,734.7	277,524
Current emissions	25.73	13,154	1,899.4	114,158
Change	**-31.1%**	**-27.1%**	**-30.5%**	**-22.8%**

Table 6-7: Air pollution and climate change indicators for Metro.

For all pollutants, the emission reductions are more significant for the Metro line than the Metrobús line. Overall, the pollutant emission reduction is 29.6% for the Metro compared to 12.3% for the Metrobús. The reduction in CO_2 emissions is also significantly higher for Metro (22.8%) than for Metrobús (4.9%). Furthermore, in absolute terms all the annual emissions are much higher for Metro and Metrobús. This can be explained by the higher number of vehicles within the zone of influence. However, this also means that the absolute emission reductions are more significant for the Metro. Hence, the effects of the Metro line on climate change and air quality is much more significant than the effects of the Metrobús line.

6.3.2 MODAL SHIFT

Table 6-8 shows the modal shift as a result of the implementation of the Metrobús line. The total number of daily trips is a little higher than the total number of daily passengers. This is the result of the passengers that previously used a chained trip of microbus and Metro. Hence, by shifting to Metrobús, both trips have been replaced. The table shows that the majority of the modal shift occurs from low-capacity public transport (combi, micro and autobus) and Metro. These two account for almost 80% of the total modal shift. Motorized private modes (car and taxi) represent 14.3% of the modal shift. This is the value that is used for the modal shift indicator. Furthermore, 1.8% of all trips is generated as a result of Metrobús implementation; these trips were not made prior to implementation. The remaining modal shift occurs from non-motorized transport (2.7%) and RTP (1.2%).

Transport mode	Daily trips	Percentage
Metrobús	0	0.0%
Foot	972	1.5%
Bike	795	1.2%
Motor	0	0.0%
Car	4,088	6.2%
Taxi	5,298	8.1%
RTP	774	1.2%
Combi/Micro/Autobus	26,581	40.5%
Trolley bus	0	0.0%
Metro	25,841	39.4%
New trip	1,210	1.8%
Total	**65,560**	**100.0%**

Table 6-8: Modal shift for Metrobús.

The modal shift that results from the implementation of the Metro line is depicted in Table 6-9. The majority of the modal shift is from the low-capacity combis, micros and autobuses. This represents 63.7% of the modal shift. A significant part (8.6%) of the Metro trips was not made previously and is generated as a result of the implementation of the line. Furthermore, 8.3% of the passengers already used the Metro previously. These passengers have probably shifted to the new line because this offers lower travel times. Motorized private modes represent 7.5% of the modal shift. This value is used for the modal shift indicator. The remaining trips were previously made by RTP (5.4%), Metrobús (2.2%), trolley bus (1.8%), motor (1.4%) and non-motorized transport (1.2%).

Transport mode	Daily trips	Percentage
Metrobús	11,626	2.2%
Foot	3,651	0.7%
Bike	2,643	0.5%
Motor	7,515	1.4%
Car	29,718	5.5%
Taxi	10,659	2.0%
RTP	29,026	5.4%
Combi/Micro/Autobus	342,116	63.7%
Trolley bus	9,491	1.8%
Metro	44,341	8.3%
New trip	46,002	8.6%
Total	**536,787**	**100.0%**

Table 6-9: Modal shift for Metro.

Significant differences exist in the modal shift of the Metrobús line and Metro line. For both the largest modal shift is from combi, micro and autobus. However, this fraction is much higher for Metro than for Metrobús; 63.7% and 40.5%, respectively. Also, the Metrobús line is characterized by a high fraction of previous Metro travelers (39.4%), while the Metro line only has a minor modal shift from Metrobús (2.2%). Furthermore, the modal shift from private modes is higher for Metrobús (14.3%) than Metro (7.5%).

6.4 ECONOMIC INDICATORS

This section discusses the results for the economic indicators. The travel time savings, construction costs, operating and maintenance costs and revenues are discussed successively.

6.4.1 TRAVEL TIME SAVINGS

The travel time savings for the Metrobús are shown in Table 6-10. The table shows that annually the total travel time savings equal approximately 19 million hours, or 2.4 million working days. This is more or less 6.6 minutes, or 11.1%, per trip. A comparison between income groups between the percentage of trips and the percentage of travel time savings shows that the first, second and fourth income groups enjoy lower travel time savings than the average. Meanwhile, the third, fifth and sixth income groups enjoy higher travel time savings than the average. This suggests that travel time savings are slightly higher for higher income groups.

The monetized travel time savings amount to over US$ 22.4 million per year (US$ 0.13 per trip) using traditional, utilitarian monetization techniques. However, using the egalitarian equity value of time, the annual monetized travel time savings are US$ 73.2 million, or US$ 0.41 per trip. This can be explained by the high fraction of travel time savings for the three lowest income groups (91.3%), while the equity VOT is between the fourth and fifth income group. Hence, the average VOT per hour is much higher for the equity value of time (US$ 3.76) than the income-dependent VOT (US$ 1.15). The percentage of monetized travel time savings per income group also shows a shift towards higher income groups, because of their higher VOT.

A more detailed study of the data shows that large differences exist between direct and indirect travel time savings, as is illustrated in Table A-6 and Table A-7 in Appendix P. Average direct travel time savings are 16.5 minutes (34.7%) or US$ 0.48 (31.3%) per trip and average indirect travel time savings are 5.5 minutes (9.1%) or US$ 0.09 (10.5%) per trip. Hence, direct travel time savings are approximately four times higher. However, the direct travel time savings represent only 24.5% of total travel time savings. This is because the number of non-users (550,604) is much higher than the number of users (59,344). Therefore, the indirect travel time savings are dominant in the total travel time savings for the Metrobús line.

Income group (MEX$)	Daily trips	Trips (%)	Annual TTS (hours)	TTS (%)	Annual TTS (US$)	Monetized TTS (%)
$0 - $1,500	58,715	9.6%	866,587	4.5%	$142,987	0.6%
$1,501 - $4,500	380,163	62.3%	9,970,424	51.2%	$6,580,480	29.4%
$4,501 - $7,500	113,718	18.6%	6,942,185	35.7%	$9,163,684	40.9%
$7,501 - $15,000	49,898	8.2%	1,101,185	5.7%	$2,725,433	12.2%
$15,001 - $30,000	4,779	0.8%	318,107	1.6%	$1,574,949	7.0%
$30,001 - $45,000	2,675	0.4%	265,457	1.4%	$2,190,282	9.8%
More than $45,000	0	0.0%	0	0.0%	$0	0.0%
Total	**609,948**	**100.0%**	**19,463,945**	**100.0%**	**$22,377,815**	**100.0%**
Average per trip (minutes)	**-**	**-**	**6.6**	**11.1%**	**$0.13**	**14.0%**
Equity VOT	**609,948**	**100.0%**	**19,463,945**	**100.0%**	**$73,203,897**	**100.0%**
Average per trip (equity VOT)	**-**	**-**	**6.6**	**11.1%**	**$0.41**	**11.1%**

Table 6-10: Total travel time savings for Metrobús.

The results of the travel time savings for the Metro line are shown in Table 6-11. The total travel time savings are almost 104 million hours per year. This equals thirteen million working days per year, or approximately 15.9 minutes per trip (21.7%). The main travel time savings are enjoyed by the first and fourth income groups, who have a higher percentage of travel time savings than the percentage of trips. However, differences are relatively small, suggesting that travel time savings are distributed relatively equally.

The monetized travel time savings amount to a total of US$ 108.5 million per year, or US$ 0.28 per trip (21.7%). Application of the equity VOT increases the monetized travel time savings to US$ 389.8 million per year, equaling US$ 0.99 per trip (21.7%). Similar to the Metrobús, this is because the majority of the travel time savings (87.0%) are made by the three lowest income groups. Once again, this effect also becomes clear by the higher percentage of monetized travel time savings than non-monetized travel time savings for higher income groups. This is confirmed by the average VOT per hour, which is much higher for the equity value of time (US$ 3.76) than the income-dependent VOT (US$ 1.05).

Table A-8 and Table A-9 in Appendix Q show the direct and indirect travel time savings, respectively. This gives insights in how the direct and indirect impacts of the Metro line differ in terms of travel time savings. The tables show that average direct travel time savings per trip are 26.4 minutes (27.1%) or US$ 0.42 (27.2%), while average indirect travel time savings are 8.8 minutes (15.6%) or US$ 0.18 (14.7%) per trip. This illustrates that direct travel time savings are over three times higher than indirect travel time savings. For monetized travel time savings, the direct impacts are over 2.5 times higher. The direct travel time savings represent approximately two thirds (66.6%) of the total travel time savings of the Metro line.

Income group (MEX$)	Daily trips	Trips (%)	Annual TTS (hours)	TTS (%)	Annual TTS (US$)	Monetized TTS (%)
$0 - $1,500	149,695	11.1%	15,487,300	14.9%	$2,555,405	2.4%
$1,501 - $4,500	641,711	47.8%	48,010,392	46.3%	$31,686,858	29.2%
$4,501 - $7,500	361,554	26.9%	26,664,437	25.7%	$35,197,057	32.4%
$7,501 - $15,000	125,814	9.4%	11,502,391	11.1%	$28,468,419	26.2%
$15,001 - $30,000	49,986	3.7%	1,779,538	1.7%	$8,810,491	8.1%
$30,001 - $45,000	8,929	0.7%	211,876	0.2%	$1,748,191	1.6%
More than $45,000	6,027	0.4%	0	0.0%	$0	0.0%
Total	**1,343,717**	**100.0%**	**103,655,935**	**100.0%**	**$108,466,421**	**100.0%**
Average per trip (minutes)	**-**	**-**	**15.9**	**21.7%**	**$0.28**	**20.3%**
Equity VOT	**1,343,717**	**100.0%**	**103,655,935**	**100.0%**	**$389,849,970**	**100.0%**
Average per trip (equity VOT)	**-**	**-**	**15.9**	**21.7%**	**$0.99**	**21.7%**

Table 6-11: Total travel time savings for Metro.

The total travel time savings for the Metro line are much higher than for the Metrobús line. This holds for both the monetized (almost seven times higher) and non-monetized travel time savings (over five times higher). Furthermore, the average travel time savings per trip are more or less 2.4 times higher for the Metro than for the Metrobús. However, if the direct and indirect travel time savings are regarded separately, results are different. Direct Metrobús travel time savings are higher than direct effects for Metro; 34.7% compared to 27.1%. On the other hand, the indirect travel time savings of the Metro are higher (15.6%) than the indirect impacts for Metrobús (9.1%). Hence, the main difference between the travel time savings is caused by the difference in fraction of users, which is much higher for the Metro line. The fraction of users signifies the percentage of users compared to all trips within the zone of influence.

6.4.2 CONSTRUCTION COSTS

The construction costs for Metrobús and Metro are shown in Table 6-12. These costs are expressed in US$ per kilometer. The Metrobús construction costs are less than US$ 1.5 million per kilometer. The Metrobús construction costs are based on the Federal District's public accounts (GDF, 2011, 2012). Meanwhile, the Metro construction costs are almost US$ 66 million per kilometer. The Metro construction costs are based on public accounts and the expenditure budget of government of the Federal District (GDF, 2008, 2009, 2010, 2011, 2012, 2013, 2014a). Hence, the Metro construction costs are much higher than the Metrobús construction costs (almost fifty times as much). The total construction costs of the Metro line were almost US$ 1.6 billion, compared to only approximately US$ 41 million for the Metrobús line.

6.4.3 OPERATING AND MAINTENANCE COSTS

The operating and maintenance costs are also shown in Table 6-12. The operating and maintenance costs for the Metrobús line are US$ 178,380 per kilometer per year. For the Metro line, these operating and maintenance costs are over US$ 1.7 million per kilometer per year. Thus, the operating and maintenance costs are significantly higher for the Metro line than for the Metrobús line (almost fifteen times higher). The total annual operating and maintenance costs for the Metrobús line are US$ 5.0 million. For the Metro, these amount to US$ 42.5 million.

6.4.4 REVENUES

The revenues for the Metro line and Metrobús line are shown in Table 6-12. For the Metrobús, the total annual revenues amount to US$ 7.5 million. This equals US$ 267,992 per kilometer of Metrobús infrastructure. For the Metro, the total annual revenues are US$ 49.6 million, which equals US$ 2.0 million per kilometer. Hence, the revenues for the Metro are more than seven times higher than the revenues for the Metrobús. Table 6-12 also shows that for both the Metrobús and Metro line the revenues exceed the operating and maintenance costs, indicating an annual cash inflow due to operating results.

Transport system	Construction costs (US$/km)	Operating & maintenance costs (US$/km/year)	Revenues (US$/km/year)
Metrobús	$1,468,890	$178,380	$267,992
Metro	$65,853,454	$1,733,957	$2,024,209

Table 6-12: Construction costs, operating & maintenance costs and revenues.

6.5 AGGREGATED INDICATORS

This section discusses the aggregation of the indicators discussed in the previous section. All the results in this previous section are summarized in Table 6-13, to provide an overview for the input for the aggregation presented in this section. First of all, the flag model is applied, which provides insights in how the indicators compare to findings of other studies and how the two systems compare. Secondly, the economic indicators are aggregated using conventional economic aggregation techniques. Finally, the efficiency of indicators is discussed. This concerns both the economic efficiency and the efficiency per passenger.

Indicator	Metrobús	Metro
Travel time savings	11.1%	21.7%
Construction costs	$1,468,890	$65,853,454
Operating & maintenance costs	$178,380	$1,733,957
Revenues	$267,992	$2,024,209
Equity	31.3%	39.8%
Safety	23.4%	29.6%
Air pollution	-12.3%	-29.6%
Climate change	-4.9%	-22.8%
Modal shift	14.3%	7.5%

Table 6-13: Overview of indicator values for Metrobús and Metro.

6.5.1 FLAG MODEL

The flag model was applied to the results. The flag model and the CTVs are elaborated on in chapter five. Briefly summarized, the flag model compares the indicator values found in this research with values found in literature. This is done using CTVs, which have a minimum, an average and a maximum value. Indicator values are within a certain bandwidth of the CTVs and are attributed a flag color accordingly. A black flag represents ‘low performance’, a red flag ‘low to medium performance’, an orange flag ‘medium to high performance’ and a green flag ‘high performance’. Furthermore, a standardized value is calculated based on the indicator value and the CTVs. The individual indicators are also aggregated for each indicator group (economic, social and environmental) and for an overall outcome. These results are represented in Table 8-1. The color of the cells represents the flag color of the indicator.

The individual indicator flags show that the Metrobús line is attributed four black flags, one red flag and four green flags. The Metro line has three black flags, four red flags and two green flags. The indicator values show that of the nine basic indicators, the Metrobús performs better at three indicators (construction costs, operating and maintenance costs and modal shift), while the Metro performs better at six indicators (travel time savings, revenues, equity, safety, air pollution and climate change). For both lines, the economic and environmental composite indicators are attributed a red flag and the social composite indicator an orange flag. The Metrobús line performs better for the economic composite indicator, while the Metro line performs better for the social and environmental composite indicator. Overall, both lines are attributed a red flag, although the standardized values show that the Metrobús system performs slightly better. However, it has to be noted that for all aggregated indicators the differences in standardized values are small.

			Metrobús		Metro	
	Indicator	Abbr.	Indicator value	Standardized value	Indicator value	Standardized value
Economic	Travel time savings	TTS	11.1%	-2.00	21.7%	-0.64
	Construction costs	CON	$1,468,890	1.12	$65,853,454	-0.49
	Operating & maintenance costs	OM	$178,380	2.00	$1,733,957	-2.00
	Revenues	RE	$267,992	-1.34	$2,024,209	1.49
	Economic	**EC**	-	**-0.05**	-	**-0.41**
Social	Equity	EQ	31.3%	2.00	39.8%	2.00
	Safety	SA	23.4%	-0.86	29.6%	-0.40
	Social	**SO**	-	**0.57**	-	**0.80**
Environmental	Air pollution	POL	-12.3%	-1.47	-29.6%	-0.53
	Climate change	CC	-4.9%	-2.00	-22.8%	-1.17
	Modal shift	MS	14.3%	1.10	7.5%	-1.09
	Environmental	**EN**	-	**-0.79**	-	**-0.93**
	Overall	**OV**	-	**-0.09**	-	**-0.18**

Table 6-14: Overview of flag model and corresponding flags for all indicators for Metrobús and Metro.

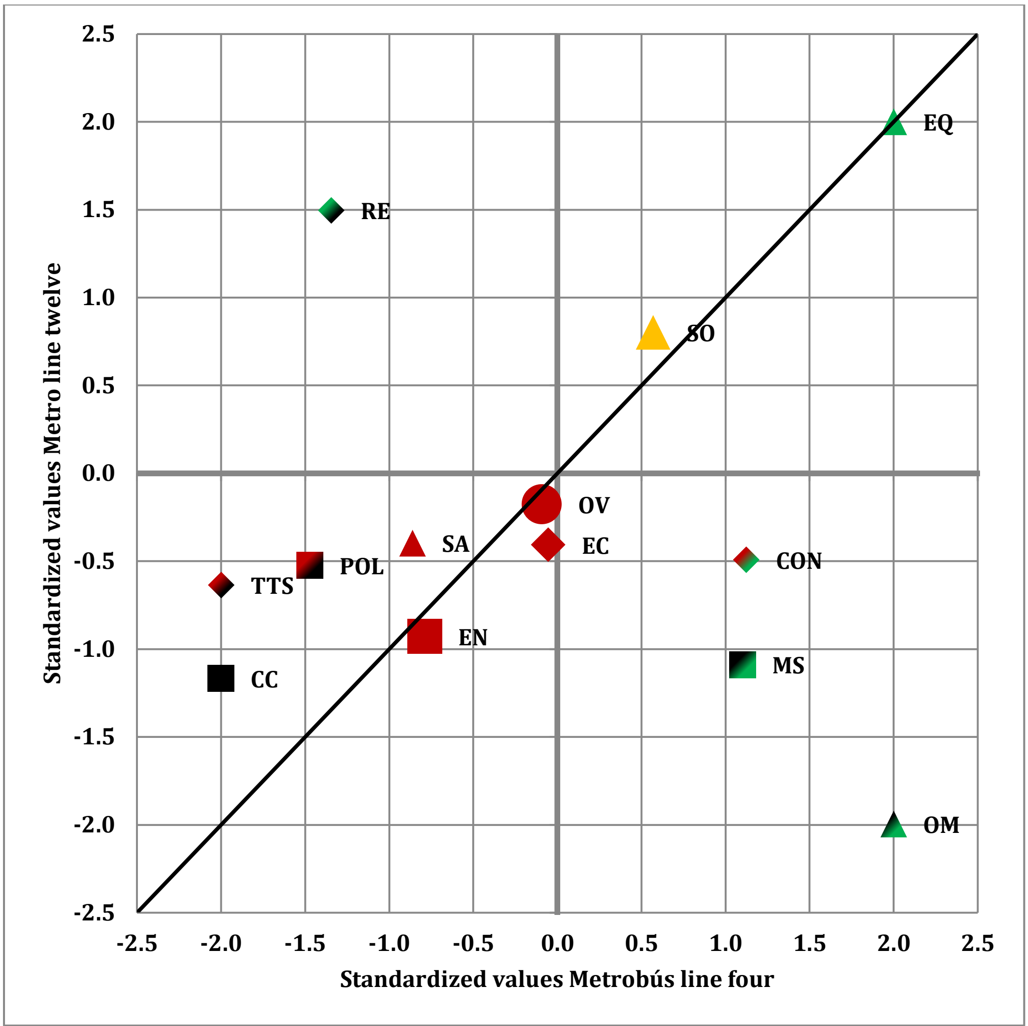

Figure 6-1: Comparison of standardized values of indicators for Metrobús and Metro.

In order to show the difference in performance between Metro and Metrobús, the standardized values of the basic and composite indicators have also been displayed in a graph. This is shown in Figure 6-1. The horizontal axis represents the standardized values of the Metrobús line and the vertical axis represents the standardized values of the Metro line. This way, the composite and basic indicators are added to the figure. Additionally, the black 45° line represents the equal division line. If a point is below this line, the indicator performs better for the Metrobús than the Metro. If an indicator is above this line, the indicator performs better for the Metro than the Metrobús. The abbreviations used for the indicators are shown in Table 8-1. The color of the markers signifies the attributed flag. A solid color means that Metro and Metrobús are attributed the same flag, while a gradient signifies they have different flags. In that case, the top left indicates the Metro flag color and the bottom right the Metrobús flag color.

This graph provides several insights in the performance of the indicators. First of all, it shows that most indicators perform below the averages found in literature (this becomes evident from most indicators being in the bottom left quarter). Secondly, there are some indicators for which the Metro performs significantly better than the Metrobús, which are positioned in the (top) left of the graph. Similarly, there are also a few indicators for which the Metrobús performs significantly better than the Metro, which are located in the bottom right. Thirdly, all composite indicators are close to the equal division line. This means that for the composite indicators, the differences in performance are small.

6.5.2 ECONOMIC AGGREGATION

The economic aggregation is only based on the economic indicators and does therefore not provide an aggregation of all the indicators included in the framework. The economic aggregation is conducted in two different ways. First of all, the equity value of time is used for the monetized travel time savings. However, since the results show that this equity value of time significantly impacts the value of travel time savings, the economic aggregation is also conducted using the traditional approach, using a value of time which differs per income group. The results of this economic aggregation are shown in Table 6-15. An overview of the economic aggregation per year for the Metrobús is shown in Table A-10 and Table A-11 in Appendix R. The same is shown for the Metro in Table A-12 and Table A-13 in Appendix S.

	Equity VOT		Income-dependent VOT	
	NPV (US$)	B/C ratio	NPV (US$)	B/C ratio
Metrobús	$541,432,394	8.48	$147,852,942	3.04
Metro	$1,449,936,616	1.77	-$728,999,439	0.61

Table 6-15: Economic aggregation for Metrobús and Metro.

The economic aggregation shows that the Metrobús has a positive NPV for both the equity (US$ 541 million) and income-dependent VOT (US$ 147 million US$). However, the NPV is much lower using the income-dependent VOT. Furthermore the B/C ratio shows that for both situations the financial investments are efficient, since both have a value well above one. For the equity VOT, every US$ that is invested results in US$ 8.48 of benefits. For the Metro, the NPV is high for the equity VOT (US$ 1.45 billion), but negative if the income-dependent VOT is used (US$ -729 million). This means the (discounted) costs exceed the benefits of the project. This is also shown by the B/C ratio, which is only 0.61 for the income-dependent VOT. The B/C ratio is 1.77 for the equity VOT, indicating that the project is profitable, but that efficiency is limited.

In terms of absolute profitability, the Metro is preferable over the Metrobús if the equity VOT is used. However, if the income-dependent VOT is used, the Metrobús line clearly performs better. Furthermore, in terms of economic efficiency, the Metrobús line performs much better than the Metro line. Economically, the Metrobús line is almost five times as efficient as the Metro. A more detailed look at the results presented in Appendix R and Appendix S explains the main differences. Both lines are comparable in the difference between revenues and operating and maintenance costs, which is slightly positive for both. However, the travel time savings are much (more or less five times) higher for the Metro than for the Metrobús. Additionally, the construction costs differ significantly, which are more than 39 times higher for Metro than for Metrobús. Hence, the influence of the construction costs on the results is especially evident for the Metro. Furthermore, the high construction costs mean that the denominator of the B/C ratio is much higher for the Metro than for the Metrobús. As a result, changes in the numerator of the Metro have a smaller effect on the B/C ratio than for the Metrobús.

6.5.3 EFFICIENCY

The economic efficiency gives an indication of the efficiency of the invested money per indicator. This economic efficiency is based on the indicator values and the construction costs. Hence, effects are expressed in terms of invested dollar. The results for the nonmonetary indicators are shown in Table 6-16. This shows that for every indicator the Metrobús is economically more efficient than the Metro. The Metrobús is especially more efficient in terms of equity and safety. Efficiency is also considerably more efficient for travel time savings, modal shift, CO emissions and NO_x emissions. Compared to the other indicators, the Metrobús' economic efficiency is only slightly higher for CO_2 and PM_{10} emissions. Nonetheless, these results clearly show that in terms of economic efficiency the Metrobús performs much better than the Metro. Meanwhile, the previous sections showed that often the effects of the Metro were higher in absolute terms. On the other hand, construction costs of the Metro are that much higher that this dominates the results.

Indicator	Metrobús	Metro
Equity (Gini-points/billion US$)	0.37	0.01
Safety (points/thousand US$)	19.65	1.09
PM_{10} (g/US$)	0.16	0.11
CO (g/US$)	159.40	45.48
NO_x (g/US$)	20.34	7.77
CO_2 (g/US$)	819.03	589.12
Modal shift (private trips/US$)	1.00	0.13

Table 6-16: Economic efficiency per indicator for Metrobús and Metro.

The economic efficiency of the travel time savings expressed in terms of construction costs is shown in Table 6-17. The table illustrates the total discounted monetized travel time savings for the entire project horizon divided by the construction costs per trip purpose. Hence, the table demonstrates the efficiency of the initial investment in achieving travel time benefits. The division into trip purposes gives an indication of which trips enjoy most benefits. The table shows that the economic efficiency is highest for the Metrobús lines. Furthermore, it is clear that commuting trips to or from work constitute the majority of travel time savings. In fact, on their own these trips are responsible for an economically efficient investment in three of the four cases. Another clear difference is the difference between the use of income-dependent and equity VOT; for the latter the economic efficiency is significantly higher. The importance of the VOT is shown more elaborately in section 6.6.1.

Trip purpose	Metrobús		Metro	
	Income-dependent VOT	Equity VOT	Income-dependent VOT	Equity VOT
Work	2.77	10.41	0.30	1.12
School	0.13	0.48	0.05	0.20
Food	0.01	0.03	0.01	0.03
Visit family/friends	0.06	0.24	0.05	0.18
Shopping	0.54	2.02	0.02	0.07
Leisure/recreational	0.12	0.46	0.03	0.11
Medical	0.04	0.14	0.04	0.16
Other	0.00	0.00	0.00	0.00
Total	**3.66**	**13.78**	**0.50**	**1.87**

Table 6-17: Economic efficiency of travel time savings per trip purpose (US$ travel time savings/US$ construction costs).

The efficiency per user trip for several indicators is shown in Table 6-18. Not all indicators are included, because for some indicators values per trip were already part of the standard results, namely safety and modal shift. Furthermore, for the equity indicator it is pointless to express the efficiency per trip, because this gives an indication of the distribution and the improvement in the equality of this distribution is not influenced by the number of passengers. The efficiency portrayed in the table is based on the average impacts per user trip. The passenger numbers were corrected for annual or full project horizon numbers depending on the indicator. Furthermore, for the travel time savings the total travel time savings were used. Hence, these savings represent the direct and indirect impacts per trip. These values give an indication of the efficiency of the project in terms of impacts per user. The main rationale for this is that the results show significant differences in the fraction of passengers of all travelers. For the travel time savings and construction costs, the Metrobús is more efficient. In terms of operating and maintenance costs and all four emission reductions, the Metro is more efficient. However, these efficiencies are more similar than the economic efficiencies.

Indicator	Metrobús	Metro
Travel time savings (minutes/trip)	67.39	39.68
Construction costs (US$/trip)	0.16	0.69
Operating & maintenance costs (US$/trip)	0.29	0.27
PM_{10} (grams emission reduction/trip)	0.03	0.07
CO (grams emission reduction/trip)	25.22	31.21
NO_x (grams emission reduction/trip)	3.22	5.33
CO_2 (grams emission reduction/trip)	129.60	404.27

Table 6-18: Efficiency per indicator for Metrobús and Metro.

6.6 SENSITIVITY ANALYSIS

This section presents the results for the sensitivity analysis. First of all, the sensitivity of some indicators is addressed. This concerns sensitivity resulting from varying values of the value of time, emission factors and equity assumptions. Secondly, the sensitivity of the flag model is elaborated on. For this, only direct effects are included, and a hypothetical capacity increase is investigated.

6.6.1 INDICATOR SENSITIVITY

The sensitivity analysis first of all analyses the effects of the value of time on the NPV and B/C ratio for the economic indicators. The results of this analysis are shown in Table 6-19. Clearly, the higher the VOT, the higher the NPV and B/C ratio. Furthermore, the income-dependent value of time results in the lowest NPVs and B/C ratios, followed by the equity VOT based on median income. The equity VOT based on average income results in the highest NPVs and B/C ratios. Furthermore, in all scenarios the B/C ratio is higher for the Metrobús. However, the NPV is higher for Metro if a VOT of 50% or 100% is used and travel time savings are calculated using the average or median income. Furthermore, for Metrobús the NPV is always positive and the difference between the lowest and highest NPV is approximately US$ 2.1 billion. For the Metro, on the other hand, the NPV is negative in some cases and the difference between lowest and highest NPV is much higher at US$ 5.6 billion.

		Metrobús		Metro	
	VOT type	NPV (US$)	B/C ratio	NPV (US$)	B/C ratio
VOT = 25%	Income-dependent	$443,480,776	7.13	-$1,148,864,074	0.39
	Equity (average; $17,095)	$791,741,686	11.94	-$59,093,139	0.97
	Equity (median; $12,028)	$619,264,449	9.56	-$506,986,013	0.73
VOT = 50%	Income-dependent	$676,555,293	10.35	-$728,999,439	0.61
	Equity (average; $17,095)	$1,372,847,789	19.97	$1,449,936,616	1.77
	Equity (median; $12,028)	$1,028,511,513	15.21	$555,756,219	1.30
VOT = 100%	Income-dependent	$1,142,823,008	16.79	$111,001,982	1.06
	Equity (average; $17,095)	$2,535,678,193	36.04	$4,469,601,476	3.38
	Equity (median; $12,028)	$1,846,387,443	26.51	$2,679,635,331	2.43

Table 6-19: Sensitivity analysis for value of time.

The results of the sensitivity analysis for the emission factors are shown in Table 6-20. From this table several interesting observations can be made. First of all, in the Metro emissions scenario the emissions reduction increases for Metrobús, but decreases for Metro. Secondly, the lower efficiency of public transport results in higher emission reductions for both transit lines. Third of all, the lower emission factors for private transport lead to lower absolute annual emission reductions, but to higher relative changes, except for the climate change indicator for Metrobús. Fourthly, the differences in relative change are low, while absolute annual reductions are much more significant.

	Metrobús				Metro			
	Air pollution		Climate change		Air pollution		Climate change	
	Change (tons/year)	Relative change	Change (tons/year)	Relative change	Change (tons/year)	Relative change	Change (tons/year)	Relative change
Standard	-493	-12.3%	-2,246	-4.9%	-5,739	-29.6%	-63,366	-22.8%
Scenario 1: Metro	-510	-11.3%	-3,967	-5.3%	-5,396	-23.6%	-27,606	-9.9%
Scenario 2: Public transport	-806	-16.5%	-5,049	-8.8%	-9,890	-34.1%	-102,043	-27.6%
Scenario 3: Private transport	-384	-13.5%	-548	-1.9%	-4,945	-34.1%	-51,021	-27.6%

Table 6-20: Sensitivity analysis for emission factors.

The results of the sensitivity analysis that was conducted for the equity indicator are shown in Table 6-21. If age is used as social characteristic along which equity is measured, then the improvement is considerably higher. However, the Gini-index is very close to zero, suggesting that the distribution is already almost perfectly equal. If education is used as social characteristic, the distribution of travel time savings is very equal as well. However, for the Metrobús this equality reduces, while for Metro this is improved. If the distribution of travel times is analyzed, then quite some inequality exists. Hence, there is great variance in travel times. Furthermore, the equity improvement found is much lower than if travel time savings are analyzed.

	Metrobús			Metro		
Equity type	Previous Gini-index	Current Gini-index	Improvement	Previous Gini-index	Current Gini-index	Improvement
Income	0.025	0.017	31.3%	0.092	0.055	39.8%
Age	-0.011	-0.031	66.0%	0.024	0.011	53.5%
Education	0.065	0.079	-21.0%	0.065	0.037	43.3%
Travel time	0.423	0.418	1.3%	0.470	0.432	8.1%

Table 6-21: Sensitivity analysis for equity indicator.

6.6.2 FLAG MODEL SENSITIVITY

Table 6-22 shows the results of the flag model if only direct effects are taken into account. It is important to note that this only affects the travel time savings, equity and safety indicators. The table shows that the travel time savings improve for both transit lines, but especially for Metrobús, since this indicator now performs better for Metrobús than Metro. As a result, the difference in economic performance is much higher for Metrobús than Metro. For the equity indicator, an improvement is made for Metro, but the equity improvement is lower for Metrobús. In terms of safety both systems perform better for only direct effects, although the increase is higher for Metrobús. As a result, both systems are now attributed a green flag for the composite social indicator, while previously this was a red flag. The overall flag for both systems has become orange and the Metrobús performs slightly better than the Metro. The change in standardized value is also higher for Metrobús, indicating that the difference between direct and total effects is larger for this transit line.

	Indicator	Metrobús Indicator value	Metrobús Standardized value	Metro Indicator value	Metro Standardized value
Economic	Travel time savings	31.3%	0.66	27.2%	0.11
	Construction costs	$1,468,890	1.12	$65,853,454	-0.49
	Operating & maintenance costs	$178,380	2.00	$1,733,957	-2.00
	Revenues	$267,992	-1.34	$2,024,209	1.49
	Economic	-	**0.61**	-	**-0.22**
Social	Equity	18.2%	1.11	50.8%	2.00
	Safety	59.8%	1.85	55.7%	1.56
	Social	-	**1.48**	-	**1.78**
Environmental	Air pollution	-12.3%	-1.47	-29.6%	-0.53
	Climate change	-4.9%	-2.00	-22.8%	-1.17
	Modal shift	14.3%	1.10	7.5%	-1.09
	Environmental	-	**-0.79**	-	**-0.93**
	Overall	-	**0.43**	-	**0.21**

Table 6-22: Flag model results for direct effects only.

If the number of Metrobús passengers is expanded to a full BRT line, based on the number of passengers of the first Metrobús line, the flag model yields significantly different results, as Table 6-23 illustrates. It is important to note that the construction costs and operating and maintenance costs have not been adjusted for to the implementation of a full BRT line. For all other indicators, except modal shift, the performance has improved significantly. Travel time savings have almost doubled, while revenues have increased more than six times, resulting in a much more positive aggregated economic result. The equity effects have in fact decreased, but the significant safety improvement still results in a more positive social performance. Although climate change performance is still under the average found in literature, this has improved considerably. The same holds for air pollution, which is reduced by 74%. Consequently, environmental performance has improved considerably. Furthermore, the results show that on all composite indicators the Metrobús line performs better and also the overall performance is significantly better than the Metro's. The only basic indicators for which the Metro performs slightly better are travel time savings, revenues and equity.

	Indicator	Metrobús Indicator value	Metrobús Standardized value	Metro Indicator value	Metro Standardized value
Economic	Travel time savings	20.5%	-0.81	21.7%	-0.64
	Construction costs	$1,468,890	1.12	$65,853,454	-0.49
	Operating & maintenance costs	$178,380	2.00	$1,733,957	-2.00
	Revenues	$1,613,999	0.83	$2,024,209	1.49
	Economic	-	**0.79**	-	**-0.41**
Social	Equity	25.5%	1.95	39.8%	2.00
	Safety	38.0%	0.23	29.6%	-0.40
	Social	-	**1.09**	-	**0.80**
Environmental	Air pollution	-74.0%	1.90	-29.6%	-0.53
	Climate change	-29.2%	-0.78	-22.8%	-1.17
	Modal shift	14.3%	1.10	7.5%	-1.09
	Environmental	-	**0.74**	-	**-0.93**
	Overall	-	**0.87**	-	**-0.18**

Table 6-23: Flag model results for increased capacity Metrobús line.

6.7 INTERVIEWS

This section presents the main findings from the interviews with transport specialists and employees of the Metrobús system. First of all, Mexico City's transport system is elaborated on. Secondly, the political context is addressed. This is followed by an evaluation of the framework developed in this study. Finally, an elaboration on the Metrobús is given.

6.7.1 THE TRANSPORT SYSTEM

Onésimo Flores explained that Mexico City's transport has undergone major changes over the past decades. In the '80s the 'Ruta 100' was dominating public transport, offering privately-owned public transport, mainly in the form of vans. As a result, transport costs were low for the local government since no subsidies were required. Over the past decades, the transport system has evolved in a more hybrid form, in which privately-owned vans and buses still play a prominent role, but also more regulated modes are offered, in the form of Metro, Metrobús, electric transport and RTP. The existence of the many vans and old buses result in many externalities, such as contamination, congestion and accidents. Compared to the previous situation, the transport system is more organized and regulated. However, costs and subsidies are also higher for the government.

One of the main issues in Mexico City's current transport system is the lack of system integration. Emelina Nava indicates that the transport system is very fragmented, both in terms of modal integration and the integration of urban planning. In terms of urban planning two main issues exist. First of all, there is a lack of integration between the Federal District and the Estado de México. Each of them has their own mayor and local government and they hardly cooperate. Onésimo Flores mentioned an example of this: the Metro system only serves the Federal District and their government does not want to extend the system to the Estado de México, because it does not benefit its own citizens. This is also one of the reasons why the latest Metro line was built in the south of Mexico City, even though transport demand is higher in the northern areas connecting to the Estado de México. Also when the ticket price was raised this was partially because the government of the Federal District did not want to subsidize so many trips from the Estado de México. Secondly, the urban plans of SEDUVI (Secretaría de Desarrollo Urbano y

Vivienda) and transport plans of SETRAVI (Secretaría de Transporte y Vialidad) are not integrated. As a result, the goals in their plans are sometimes contradicting. This can, for example, lead to urban development occurring in a location while no additional transport is provided which results in a shortage of transport supply. Furthermore, construction works that are executed are fragmented and do not align with other plans.

Emelina Nava explained that in terms of modal integration, there is a lack of transfer terminals. Currently CETRAMs (Centros de Transferencia Modal; Modal Transfer Centers) are constructed in Mexico City, which provide some improvement. However, more improvement is required. This is especially crucial for trips between the Estado de México and Distrito Federal, which are often undertaken by a combination of Metro and microbus. Those people spend over two hours per day on transport, greatly reducing the efficiency of the city. Furthermore, some of Mexico City's transport systems are competing instead of supporting each other. For example, the third line of the Metro and the third line of the Metrobús run on the same corridor. The Metrobús visit showed that for the Metrobús more integration with NMT, and bicycles in particular, is implemented. For example, the newest Metrobús line has equipped most stations with bicycle parking facilities and a bicycle path parallel to the corridor. However, they also indicate that to improve intermodal transport, it would be more efficient to implement perpendicular bicycle paths that provide access to surrounding neighborhoods. This way, the bicycle is stimulated as access mode, instead of competing mode. Emelina Nava indicates that one of the largest successes of transport integration in Mexico City is the payment integration with the chip card. However, Onésimo Flores notes that fare integration between the various transport modes is still missing. As a result, many of the trips between the Federal District and Estado de México have higher costs, because multiple modes are used.

6.7.2 POLITICAL CONTEXT

Onésimo Flores explained that the political situation in the Federal District is unique in Mexico. Until 1997 mayors were not elected; because the Federal District is part of the federal government, they appointed a mayor. Since 1997 mayor elections have been held in which the mayor is elected for a term of six years. Emelina Nava highlights that each mayor can only be elected once and that when a new mayor is elected, new plans for the city are made and all civil servants at the ministries are replaced. Therefore, most of the planning in Mexico City is short-term, because mayors want the benefits of (transport) projects to be acquired while they are still in office. This means that there are almost no long-term plans for the city, although Onésimo Flores indicates that the Metrobús is an exception to this. Additionally, Emelina Nava mentions that the interest of politicians in the Metrobús project largely determines if new lines are implemented. Moreover, the last three mayors belonged to the same left-wing political party that favors Metrobús, explaining the rapid increase in the Metrobús network. On the other hand, Mexico's previous president was right-winged and against Metrobús implementation.

Emelina Nava mentioned that there is a national infrastructure fund to which municipalities can apply for support in the construction costs. The Metrobús and especially the Metro system are largely dependent on this fund, due to the high implementation costs. As a result, these transport projects are often part of national political negotiations. For example, the current national president is of a different political party than the mayor of the Federal District, which makes it difficult to attain funding for Metrobús projects. Contrarily, before the mayor election was democratized, much of the Metro infrastructure was paid for by the national government, because they were of the same political party. After the democratization, many cities raised the questions why the Federal District received aid, but many other cities did not. This explains why only one new Metro line was constructed since then even though in the seventies a Metro system of twenty lines and 400 kilometers was planned.

Emelina Nava believes political aspects are considered the most important in the decision making process. However, Onésimo Flores highlights that political goals often incorporate other goals, such as economic, social and environmental objectives. Furthermore, the expected demand on a corridor and the ease of implementation are important decision factors. The latter includes, for example, the number of existing operators on a corridor. Emelina Nava notes that environmental factors are also important to receive international funding. The Metrobús visit showed that although this does not amount to much financial aid, approximately one million euros for the entire operation period, it is nonetheless important to confirm the innovative properties of the system to sell the project to voters. For the Metrobús, the most important factor to consider where new lines are constructed is passenger demand. Furthermore, there are some limitations to where lines can be constructed, due to the geographic properties. For example, the twelfth Metro line is the farthest south a mass transit line can be constructed, due to the mountainous characteristics of that area. As an alternative, the government often provides RTP to such areas at low prices, sometimes as cheap as two pesos, because these are often low income areas.

6.7.3 EVALUATION FRAMEWORK

Emelina Nava indicates that of the indicators in the framework, travel time savings are very important. However, these should include transfer times between modes and the transfer time per mode. This allows for an evaluation of how these travel time savings are acquired. Furthermore, this gives an indication of the efficiency of the transport system. Furthermore, Emelina Nava suggests including the relation between the capacity and the demand of the line. Onésimo Flores agrees on the indicators in the framework, but notes that the framework only incorporates the impacts of one line and not the entire network. However, the impact of a transit line on the entire transit network may also be significant. Additionally, the fourth line of the Metrobús is a very specific case, because it uses on-board fare collection and stops instead of stations. Also, it competes with the many Metro lines in the historic city center and has a low demand compared to other Metrobús lines. He expects this significantly influences the results.

Onésimo Flores and Emelina Nava agree that ex-post evaluations are useful and necessary, especially to improve future projects. Results can be used to improve the planning of future lines that are implemented. This is especially useful for the Metrobús, for which at least five additional lines are planned. Such evaluations are particularly useful for technical and planning improvements. On the other hand, both transport specialists note that politicians are more interested in the implementation of new lines than the evaluation of existing lines. Furthermore, outcomes are only used if they are in line with existing plans. Hence, politicians mainly use such evaluations to legitimize their decisions were correct. Nonetheless, Onésimo Flores indicates that ex-post evaluations are politically useful to communicate the benefits of such systems. Such communications can be used to convince operators and others of the positive impacts such transit lines have. Furthermore, while ex-ante appraisal is obligatory in Mexico, ex-post evaluations are only conducted rarely, making this study very interesting.

6.7.4 METROBÚS

The Metrobús visit revealed that the negotiations with the operators were most difficult for the first lines. For the more recent lines, including the fourth, the acquired experience has made negotiations easier. Furthermore, the payment per kilometer is more or less established, which makes room for negotiations smaller. Onésimo Flores indicated that there were some protests from neighbors for the implementation of the fourth line. Additionally, interest to participate was low amongst operators. Another important characteristic of the line is that the line did not exist in original Metrobús plans. Therefore, the main reason for implementation seems to be renovating and recuperating the historic center. Moreover, Onésimo Flores suspects that part of the rationale for the line was to decrease the demand for the extremely busy Metro lines one and two, which operate in the same area and compete with the Metrobús line.

The goals that were set for the implementation of the Metrobús line four include a modal shift, a travel time reduction of 40% and improved integration with other mass transit modes. The Metrobús officials claim that a modal shift from car of 12,000 daily passengers is achieved, which equals 17%. Therefore, they believe the modal shift goal has been achieved. Travel times reduced from one hour to half an hour, or 50%. Hence, the travel time reduction objective has been realized. Furthermore, travel time reliability has improved significantly, especially compared to micros. On the other hand, some streets are now exclusive for Metrobús, which results in longer trips, although this is nullified by the higher speeds. Concerning the modal integration, the Buenavista and San Lázaro terminals provide integration with the commuter train and an intercity bus terminal, as well as the Metro and other Metrobús lines. Furthermore, along the route modal integration is accomplished with the Metro and Metrobús system. Thus, the Metrobús organization believes modal integration has been attained. However, stations are not physically integrated, which means that for transfers roads have to be crossed. Furthermore, due to the low-floor design of the fourth Metrobús line, physical integration with the other lines, which have a high-floor design, is impossible. Currently, real time travel information is tested for line four, which will provide information on the arrival of the next bus. This gives passengers the option to shift modes if the arrival takes too long. Finally, an expected annual GHG emission reduction of 10,000 tons per year is realized due to the construction of line four.

Onésimo Flores, on the other hand, expects that results for the line are minimal, especially because of the low demand. Furthermore, travel time savings are lower than for other Metrobús lines because of the on-board fare collection and lower operating speeds than for other Metrobús corridors. Emelina Nava expects that the higher fare for the airport service significantly reduced the demand for that section of the line. Additionally, although the line connects with three major arterials, the modal integration at those arterials is suboptimal.

Some other characteristics of the Metrobús that were discussed during the interviews showed that the system lacks some properties for optimal implementation. First of all, Emelina Nava explained that the system lacks feeders, which means that passengers have to use other transport modes to access the Metrobús system. Unofficially microbuses do offer some sort of feeder service, but this is not regulated and fares are not integrated. Since modal integration is limited the potential number of passengers is not acquired. Secondly, the system does not offer an express service, which does not stop at all stations and offers increased efficiency. Thirdly, no double lanes are present at stations, which means buses cannot pass each other. Also, in case of an accident, this means that buses cannot pass. Fourthly, the Metrobús visit revealed that at traffic lights no preference is given to Metrobús, which means that they often wait for a long time. This is worsened because no elevated bus lanes were implemented, so every intersection uses traffic lights. Furthermore, only few pedestrian bridges exist, which means that passengers have to cross the road by traffic lights, increasing travel times for passengers and buses alike. On the other hand, Emelina Nava highlights that the first Metrobús line has a capacity rivalling that of the Metro, indicating that potentially a Metrobús line can achieve similar effects. Furthermore, ten Metrobús lines can be constructed for the same costs of one Metro line.

6.8 CONCLUSIONS

This chapter has presented many results from the application of the methodologies discussed in chapter five. Some overall conclusions can be drawn from these results. First of all, the Metro line performs better on the following indicators: equity, safety, air pollution, climate change, travel time savings and revenues. Meanwhile, the Metrobús outperforms the Metro in terms of modal shift, construction costs and operating and maintenance costs. Aggregation of these indicators shows that the Metro performs best on social indicators, while the Metrobús performs better on environmental and economic indicators. Overall, the two lines perform similarly, although the Metrobús performs slightly better. However, the results also show that the direct effects differ significantly from the indirect effects, particularly for the Metrobús. Furthermore, in general the attributed flags portray a negative performance. The sensitivity analysis shows that results are sensitive to changes in the assumptions made in the previous chapter. This is especially true for the absolute changes and to a lesser extent for the relative change. This analysis also indicates that the sensitivity of the flag model is high. Explanations for all these conclusions are given in the following chapter. Finally, the interviews give insights in the political context of transport planning and the transport system itself. The main conclusion from these interviews is that integration (both modal integration and integration of plans) is lacking. Furthermore, politics play an important role in the decision making process of transport projects, in which local and national governments often disagree, and new mayors often alter previous transport plans. This context provides an important background for the recommendations presented in the following two chapters.

CHAPTER 7. DISCUSSION

This chapter discusses the results that were presented in the previous chapter. First of all, the individual indicators are addressed. This section focuses on how the outcomes compare with other values found in literature and also explains why the results are found. Secondly, the aggregated indicators are discussed. This concerns the aggregation using the flag model and other aggregation methods. Thirdly, the sensitivity analysis is elaborated on. Fourth, the results are presented in relation to the political context of Mexico City. Finally, some limitations of the research that do not directly result from the first four sections are mentioned.

7.1 INDIVIDUAL INDICATORS

This section compares the results of the two corridors and explains why the two lines perform differently or similarly. If applicable, a further distinction is made between direct and indirect impacts. Also, a comparison with findings in literature and, if possible, with the ex-ante appraisal is made. This section sequentially discusses the social indicators, environmental indicators and economic indicators.

1.1.1 SOCIAL INDICATORS

This section discusses the results of the social indicators. First, equity is elaborated on and consequently safety is addressed.

7.1.1.1 EQUITY

In section 6.2.1 it was shown that equity improved after the implementation of both the Metrobús and Metro line, although the improvement is higher for Metro. First of all, a possible explanation for the Metro's higher equity improvement is that the average income of the Metro user sample is lower than that of the non-user sample, while this is reverse for the Metrobús sample. Since direct travel time savings, and thus changes in travel time, are significantly larger than indirect travel time savings, the effect on low-income groups is larger for Metro than Metrobús. Additionally, it is important to note that the Gini-indices are very low (close to zero), which means that even a slight change in the value of the Gini-index significantly impacts the relative change. Secondly, the Gini-index is lower for the Metrobús than the Metro, suggesting that inequalities in travel time savings are lower for the Metrobús. An explanation for this could be the homogeneity of the sample. A more homogeneous sample means smaller variations in income groups exist, which can be a proxy for smaller variation in travel times per income group and thus a lower Gini-index. However, the Metrobús sample is more heterogeneous than the Metro sample, which suggests the Gini-index should be higher. Thus, the lower Gini-index for the Metrobús is caused by something else. Consequently, since the Gini-index is measured by the distribution of travel times over income groups, this distribution is apparently more equal for the Metrobús than for the Metro.

The equity improvements found in this research are much larger than the equity improvements (4.3%) due to land use changes and transport improvements studied by PROPOLIS (2004). Also the findings by Thomopoulos and Grant-Muller (2013) suggest much lower equity increases. This study concerned the equity effects of the European transport network and found a decrease in equity of 1.8%. On the other hand, Monzón et al. (2013) find an improvement in equity of 23.1% for the rail network in Spain. These effects are more comparable to the benefits in this research. However, the study for Spain focuses on equity improvements for accessibility, while this study evaluates equity based on changes in travel time. The other studies also use different methodologies to evaluate equity, since they do not regard the distribution of travel time savings but of other impacts, such as noise and emissions. This makes it difficult to compare the results in a detailed manner.

The equity indicator shows that for Metrobús the indirect equity improvement is significantly higher than the direct improvement. Hence, it seems the direct travel time savings are more equally distributed than indirect travel time savings. The data shows that almost all users enjoy travel time savings from the new lines. Meanwhile, many other travelers do not enjoy such benefits and experience no change in travel times. Hence, more variation occurs for indirect impacts, which apparently mainly benefits the lower income groups. The direct travel time savings are more significant, but apparently also more equal, which explains why the change in the direct Gini-index is only minimal. For the Metro, on the other hand, the direct equity improvements are higher than the indirect impacts. This is due to a higher variation in direct travel time savings, which are much larger than indirect travel time savings.

Furthermore, for both lines the direct Gini-index is lower than the indirect Gini-index, suggesting that greater inequalities in travel times exist for other travelers using different modes. For the Metro, this can be explained by the variation in the income group of the respondents, which is lower for the users than for other travelers. Hence, for users the travel times are averaged for a few large income groups, while for other travelers the travel times are more distributed over the income groups. This means that the indirect effects of differences in travel times between groups are larger than direct effects. However, for the Metrobús, this does not hold as income variation is higher for users than other travelers. An explanation for this difference is that for the Metrobús the average travel time is much higher for other travelers (60.3 minutes previously, 54.8 minutes currently) than users (47.7 minutes previously, 29.0 minutes currently). Furthermore, the variation in indirect travel time is higher than the variation in direct travel times. Consequently, the indirect Gini-index is higher, because this enhances greater differences between average travel time per income group. This explanation does not hold for Metro, as direct travel time variations are higher than indirect travel time variations. Additionally, direct travel times are higher (97.5 minutes previously, 69.3 minutes currently) than indirect travel times (56.5 previously, 47.7 minutes currently). Thus, for both lines a different reasoning explains the higher direct Gini-index.

The absolute values of the Gini-indices indicate that equality in travel time savings is very high for both Metro and Metrobús. For both lines the Gini-index is close to zero, suggesting almost perfect equality. This is remarkable, given the great income inequalities that are presented in chapter four. For the Federal District, the Gini-index is 0.413 (INEGI, 2012). Hence, the inequalities that exist within income groups are not as large for the travel time savings. This means that both transit lines make Mexico City a more equal city. This is especially interesting for the Metro, which connects two of the poorest boroughs with one of the most prosperous boroughs. Given the improvement of equity, the Metro line succeeds in providing benefits to the most vulnerable groups. Meanwhile, the Gini-index of approximately zero suggests that also the more prosperous groups enjoy significant benefits. The Metrobús connects two boroughs that do not differ as much in terms of poverty. However, the equity improvement suggests that the major benefits are attributed to the poorer segments of the population. Thus, more equality is created due to its implementation. Nonetheless, this does not mean that travel times are distributed equally for the entire city, because in locations where no mass transit system is available, larger travel time differences between transport modes may exist, causing higher inequality.

7.1.1.2 SAFETY

The results in section 6.2.2 show that for both the Metrobús and Metro safety perception improved considerably due to the implementation of both systems. This improvement is highest for the Metro, although in absolute terms, the safety improvement is more or less equal. Hence, the difference in safety improvement is mainly caused by the value of the previous safety perception. This is higher for Metrobús than for Metro. As a result, the relative safety improvement for the Metro is higher even though in absolute terms the safety improvement is similar. This also implies that the safety perception is higher for Metrobús than for Metro. This suggests that travelers on the Metrobús corridor feel safer than travelers on the Metro corridor. This includes all travelers, so also those not using the Metro or Metrobús. This is surprising, since the lack of conflicts with other modes would suggest the Metro is a safer system than the Metrobús. Nevertheless, travelers apparently do not experience it this way.

As the red flags suggest, in terms of safety the Metro and Metrobús perform lower than results from other literature. Average safety improvements are 34.9% (Breakthrough Technologies Institute, 2012; Duduta et al., 2012; Felipe Ochoa y Asociados, 2012; Litman, 2012; NYC Global Partners, 2012; PROPOLIS, 2004), which is much higher than the values found in this study. However, it is important to note that literature studies the change in the number of accidents. Meanwhile this study uses the safety perception of users and other travelers as proxy for safety, because time limitations and data availability did not allow for evaluation of the change in the number of accidents. However, to improve comparability and accuracy this is recommended for future studies. The problem with using safety perception is that it is uncertain if the score is proportional; i.e. if an improvement from four to six is the same as an improvement from eight to ten. It could very well be the case that respondents regard the change between nine and ten much more significant than the change between four and five. Hence, a safety score improvement of 25% could in fact be experienced as a 40% (or 15%) improvement, depending on how respondents value the scores. Additionally, because the relative change is used, an improvement from two to four is equal to an improvement of five to ten, even though in absolute terms the latter is much more significant. This means that a comparison with other studies is difficult.

The results of the safety indicator show that for both transit lines the direct safety improvement is more significant than the indirect safety improvement. This result was expected, because the changes in the transport system are more significant for user trips than other trips. Users experience a completely new transport system, which is of higher quality and is segregated from other traffic (using segregated lanes for Metrobús and completely segregated infrastructure for Metro), implying higher safety and thus higher safety perception. Meanwhile, other travelers only benefit from a decrease in traffic on the roads that are used. This means the likelihood of conflicts decreases, but this effect is only marginal compared to the effect of a modal shift. Hence, the difference between direct and indirect effects is logical. Another difference is the absolute value of the safety perception, which is higher for users than non-users (except for the previous safety perception of Metrobús, for which the direct safety perception was set equal to the indirect safety perception due to data limitation). This can be explained similarly as the safety improvement difference, because previous safety perceptions are more or less equal.

Finally, the absolute values of the safety indicators suggest that safety perception is higher for Metrobús than Metro (both for direct and indirect impacts). The higher non-user safety perception can be explained by the high share of Metro travelers for the Metrobús corridor, while for the Metro corridor mainly low-capacity public transport is used. Safety perception is expected to be higher for Metro users than microbus, combi or autobus. Hence, a higher indirect safety perception for Metrobús is plausible. However, the higher direct safety perception for Metrobús than Metro was not expected. Accident occurrence for the Metro is non-existent, while for Metrobús the occurrence of an accident is more likely. Hence, it was expected that the safety perception for Metro would be higher than for Metrobús. A reason for the difference can be that respondents (subconsciously) included on-board safety in their response. Hence, effects such as crowding may have been included in the safety perception, which will be more evident on the generally more crowded Metro. Once again, this confirms that using the more objective change in accidents is preferable for future studies.

7.1.2 ENVIRONMENTAL INDICATORS

This section discusses the environmental indicators. First of all, the air pollution impacts are addressed. After that, the climate change effects are elaborated on. Finally, the modal shift is discussed.

7.1.2.1 AIR POLLUTION

The previous chapter shows that the air pollution reduction is higher for Metro than for Metrobús. The explanation for this difference is threefold. First of all, there is a significant difference between the two transport systems. The Metro's propulsion is electricity-based and therefore no mobile emissions occur. Meanwhile, the Metrobús is fuel-based and therefore mobile emissions are emitted. Since this study only includes mobile emissions, and not the point emissions resulting from electricity generation, the emissions due to operation of the two lines differ greatly. Secondly, the modal shift influences pollutant emissions. The emission factors presented in chapter five show that trips by private modes (car, taxi and motorcycle) are most polluting. Also, trips by RTP, microbus, autobus and combi are more polluting than trips by Metrobús and Metro. The modal shift from private modes is higher for Metrobús than for Metro. This would indicate that the air pollution reduction would be higher for Metrobús. However, a major part of Metrobús modal shift also occurs from non-polluting modes (Metro, NMT), while this is only marginal for Metro. This difference explains the higher air pollution reduction for Metro. Third of all, the magnitude of the modal shift is much larger for Metro than for Metrobús. For Metro, the users represent 40.0% of all travelers, while this is only 9.7% for Metrobús. Since the air pollution results from the modal shift, the effects of the Metrobús users on the total air pollution emissions in the zone of influence are much smaller than the effects of the Metro users.

Other studies have also investigated effects of transit systems on air pollution. The average emission reductions found in other studies is 39.2%, although reductions range considerably between 12% and 71.4% (Felipe Ochoa y Asociados, 2012; NYC Global Partners, 2012; PROPOLIS, 2004; Turner et al., 2012). These pollutant emission reductions are much higher than the emission reductions found in this study, especially those for Metrobús, even though three of the four studies concern similar cities (Bogotá, Mexico City and Monterrey). However, NYC Global Partners (2012) measures air pollution exposure and Felipe Ochoa y Asociados (2012) measures air pollution cost reductions. Since a minimum concentration level is not harmful, these reduce more quickly. Hence, these reductions do not accurately represent the change in pollutant emissions, because for both the change is expected to be exponential instead of linear. For example, a 30% pollutant emission reduction may result in a 50% emission cost reduction. This makes it difficult to compare the results of those studies with the results of this research. The other two studies show pollutant reductions that are similar to the reductions found in this study. This suggests that the results found in this study are probable.

For air pollution, no distinction has been made for users and travelers using other transport modes, because no emission reductions are caused by the latter. However, the indicator is built up of several pollutants; PM_{10}, CO and NO_x. Some differences between these pollutants exist. For the Metrobús line, the emission reduction is equal for CO and NO_x, but smaller for PM_{10}. This is caused by the ratio between the emission factor of the Metrobús compared to the other transport modes. The proportional PM_{10} emission factor of the Metrobús is higher than the CO and NO_x emission factors, if these are related to the average emission factor of other transport modes. Hence, the Metrobús PM_{10} emission factor is relatively high compared to the CO and NO_x emission factors and therefore the PM_{10} emission reduction is lower for Metrobús. For the Metro line, pollutant emissions are almost equal, although some minor differences do exist. The emission reduction is highest for PM_{10} and lowest for CO, while NO_x is in between. The majority of modal shift occurs from microbus, autobus and combi (63.7%). For this transport mode, the emission factor of PM_{10} is highest compared to the average for all modes, while the CO emission factor is lowest and the NO_x emission factor is in between. Since the effects of this transport mode represent the majority of the overall results, it is logical that the PM_{10} emission reduction is highest and the CO emission reduction lowest.

In absolute terms, the pollutant emission reductions are much more significant for the Metro line than the Metrobús line. This was expected, because the number of users, and thus the number of replaced trips, is much higher for Metro than Metrobús. Compared with the annual pollutant emissions resulting from the transport sector, as presented by Comisión Ambiental Metropolitana (2011), Metrobús pollutant emission reductions represent approximately 0.01%, 0.03% and 0.04% of total transport emissions for the MCMA. Thus, this reduction is negligible. Unfortunately, the ex-ante appraisal of the Metrobús line did not include the air pollution effects (SOBSE, 2011), so comparing with this appraisal is not possible.

The ex-ante appraisal conducted by Spectron Desarrollo (2009) estimates the expected changes in annual pollutant emissions. This study shows that the expected annual PM emission reduction was 5.9 tons. This ex-post evaluation shows that this effect is almost double with 11.6 tons per year. For CO the estimated emission reduction was 41.7 tons per year, while this evaluation shows the reduction is 4,891 tons, over one hundred times higher. The NO_x reduction that was found in this research was over 835 tons per year, while the estimated annual emission reduction was almost 76 tons, over ten times less. Hence, for all pollutants, the emission reductions have been much higher than anticipated in the ex-ante appraisal. This difference can be explicated by the difference in modal shift. The ex-ante appraisal estimated that the reduction in vehicle kilometers due to the implementation was similar for microbus, autobus and combi and taxis, while this study shows that the modal shift from the former is much more significant. Since the emission factor per kilometer is higher (up to ten times) for microbus, autobus and combi, the emission reductions are also significantly higher. Additionally, the actual number of daily passengers is slightly higher than the expected number of passengers. Compared to the total pollutant emissions in the MCMA, effects are small, representing a reduction of 0.3% for PM_{10}, 0.3% for CO and 0.5% for NO_x. However, considering the size of the Metro line and the entire MCMA, these effects certainly have some impact on the city, and will improve air quality especially in the neighborhoods adjacent to the transit line.

This research uses average emissions factors per trip differentiated per transport mode. Hence, the assumption is made that, especially for public transport and taxi, the number of vehicles decreases if the passenger demand decreases. For example, if the average number of daily passengers on a microbus is five hundred passengers and the number of trips is reduced by ten thousand, the assumption is made that twenty microbuses stop circulating. However, in reality all microbuses may still operate with a lower number of daily passengers (e.g. 450). This means that no reduction in emissions would be caused by the modal shift. The same holds for taxis, since they may continue to drive with fewer passengers. Additionally, the assumption is made that the average trip length for the population is the same as the average trip length for the entire MCMA. However, trip lengths may differ significantly. For example, the Metro line twelve serves some outlying neighborhoods of Mexico City, suggesting longer trips than those by Metrobús line four, which serves the city center. This means that emission reductions for Metro would be somewhat higher. On the other hand, trip length may also change due to modal shift and it is difficult for respondents to estimate trip lengths if they are not driving themselves. Nonetheless, for comparative purposes this method does provide a good indication of the magnitude of air pollution reductions. Furthermore, this calculation method was the best option for this study because of its time efficiency. However, for future studies aiming at accurately measuring changes in air pollution, it is recommended to use the change in vehicle kilometers resulting from the modal shift.

7.1.2.2 CLIMATE CHANGE

CO_2 impacts are most significant for Metro. The explanation for this difference is the same as for the air pollution indicator. Hence, the intrinsic transit system emissions, difference in modal shift and the magnitude of the modal shift are the three reasons why the emission reductions differ to such large extent. Climate change effects are included in many studies, but reductions differ greatly. On average, climate change emission reductions are 42%, but reductions vary between 2.3% and 83% (Breakthrough Technologies Institute, 2012; Doll and Balaban, 2013; PROPOLIS, 2004). The CO_2 emission reductions found in this study are small compared to this average, particularly for the Metrobús. Especially in comparison with other BRT systems in Latin America the emission reductions are low, because for those systems average emission reductions are as high as 55%. However, most of these studies use estimated emission reductions and are based on CDM application. Since the estimations partially determine if CDM funding is granted, it is not unlikely that a positive scenario is presented and emission reductions are overrepresented to ensure the project is approved. Thus, actual emission reductions may be lower than these estimations. For example, Breakthrough Technologies Institute (2012) notes that the expected CO_2 emission reduction was 61.8%, while the actual emission reduction was 56.2%. This was mostly due to a decrease in the baseline emissions. If emission reductions are also lower for other BRT systems, then the Metro performance will be more comparable to the literature values. Nevertheless, the emission reduction by the Metrobús remains very low compared to other studies. Interestingly, Breakthrough Technologies Institute (2012) studied the first three Metrobús corridors and found a 40% reduction, which is much more than this study finds for the fourth Metrobús line. However, the first three corridors were full BRT lines, while the fourth is not.

In absolute terms the decrease in CO_2 emissions is much more significant for the Metro than the Metrobús. Compared to all transport CO_2 emissions in the MCMA, this reduction is marginal at only 0.3% for Metro and 0.01% for Metrobús. Hence, both transport systems do not have a large impact on the effects Mexico City's transport has on climate change. Unfortunately, the CBA of the Metrobús does not include climate change effects (SOBSE, 2011). However, the Metrobús visit showed that the expected annual GHG emission reduction was 10,000 tons. Hence, the actual reduction is more than four times lower. The ex-ante appraisal for the Metro by Spectron Desarrollo (2009) shows that the expected decrease in CO_2 emissions was 21,677 tons per year. The CO_2 emission reduction found in this study is almost three times as large. Hence, the actual impacts on climate change are much larger than the estimated effects. The same explanation for this difference as for the difference in air pollution is applicable. Furthermore, similarly as for the air pollution indicator, it is recommended to use absolute changes in vehicle kilometers to more accurately determine CO_2 emission reductions.

7.1.2.3 MODAL SHIFT

The modal shift presented in the previous chapter shows that the modal shift from car and taxi is significantly higher for the Metrobús line than the Metro line. This difference is mainly caused by the modal shift from taxi, which is much higher for Metrobús, while the modal shift from car is almost equal. This dissimilarity can be explained in two ways. First of all, the Metrobús and Metro lines serve different parts of the city. The most particular characteristic is that the Metrobús line serves the airport, a bus terminal and the city center, while the Metro line serves none of those. Especially the service to the airport is important, because those passengers most likely carry large-size luggage which is unpractical in conventional public transport. Therefore, many passengers may have used a taxi to arrive or depart from the airport. The Metrobús offers a safe alternative (there is always a policeman aboard the Metrobús from the airport), that is cheaper and provides sufficient space for luggage, since there are separate luggage racks in the bus. Hence, a significant part of taxi passengers from the airport may have shifted to Metrobús. This argument does not hold for the Metro line, explaining the difference in modal shift from taxi. Secondly, the image of the two systems is different. In Mexico City, the sentiment is that the Metro is for the poor and the system has a more massive appearance. Contrarily, the Metrobús, and especially line four, has a more modern appearance and higher visibility within the city. Thus, the Metrobús may be more appealing to travelers with higher incomes. This is confirmed by the average income of Metrobús and Metro users, presented in the previous chapter, which is almost double for the Metrobús. Since higher income groups are more likely to be able to afford, and thus use, a taxi it makes sense that the modal shift from taxi is higher for Metrobús than for Metro. A higher income also influences car ownership, as chapter four showed. Hence, it was expected that also the modal shift from car would have been higher for Metrobús than Metro, but this difference is small. Possibly this is due to the narrow streets of the city center which discourages car ownership and stimulates taxi use.

Other studies that include the modal shift as a result of BRT or MRT implementation show similar results, with car and taxi modal shifts ranging between 4.4% and 18% and averaging at 10.9% (Alpkokin and Ergun, 2012; Breakthrough Technologies Institute, 2012; Deng and Nelson, 2013; Doll and Balaban, 2013; Instituto Nacional de Ecología, 2006; NYC Global Partners, 2012; Vincent and Callaghan, 2007). Most of these studies only study the modal shift from car. Hence, a comparison with the findings of this research may overestimate the effects of the Metro and Metrobús lines. However, the taxi is most likely often left out because of its low use. For example, taxi use is much more common in Mexico than in the U.S.A. due to differences in car ownership levels and taxi prices (both of which are higher in the U.S.A.). Compared with modal shifts in other studies, especially the Metrobús performs above average, but the Metro line performs below average (which the flag model also indicates). Another interesting observation is that the modal shift from car is highest for Los Angeles (Vincent and Callaghan, 2007), which is located in one of the most motorized countries. Hence, it seems that a higher motorization results in a higher car modal shift, because the likelihood of a transit passenger owning a car is higher.

The modal shift of all transport modes shows reveals some additional insights in the two transit lines. First of all, for the Metrobús, no users used the system previously, while for the Metro this is 8.3% of the modal shift. Hence, only for the Metro travelers have changed their route, but not their mode. This is reasonable, because the Metro offers more routes than the Metrobús due to its larger network, making transfers more interesting. Secondly, the number of trips generated due to implementation is higher for Metro than Metrobús. Once again, this is sensible, because of the larger network the Metro offers. Hence, once the Metro system is entered, more travel options are available than for Metrobús. Thirdly, for both Metro and Metrobús, the modal shift from non-motorized transport is minimal. This is in line with the modal split for the entire MCMA (Ciudad de México, 2007). Fourth of all, the modal shift from Metro to Metrobús is significant, while the modal shift from Metrobús to Metro is minimal. This can be explained by the large percentage of previous Metro trips within the zone of influence of the Metrobús (almost 75%). Hence, a large modal shift from that mode is expected, especially because the Metrobús line traverses several Metro lines. The Metro line, on the other hand, only traverses the Metrobús line once (when it crosses Insurgentes Avenue), explaining the low modal shift from Metrobús. Fifth, and finally, for both lines the largest modal shift occurs from microbus, autobus and combi. Combined with RTP and trolleybus these represent 70.9% of the Metro modal shift and 41.7% of the Metrobús modal shift. This is in line with the previous modal split, for which those modes represented 81.7% and 18.2%, respectively. For the Metrobús the previous modal split may seem low, but this equals 71.3% of the modal split excluding the Metro. Since Metro passengers only traversing the zone of influence of the Metrobús line are unlikely to shift mode, the public transport modal shift is credible.

7.1.3 ECONOMIC INDICATORS

This section discusses the economic indicators. First of all, the travel time savings are addressed. This is followed by a discussion of construction costs, operating and maintenance costs and revenues.

7.1.3.1 TRAVEL TIME SAVINGS

The travel time savings for the Metro are higher than those for the Metrobús. This difference is caused by the fraction of users of the total population, which is much higher for Metro, as was already mentioned before. For both lines, the direct travel time savings are higher than the indirect savings. Since the fraction of Metrobús users is less than one tenth of the total population, the total travel time savings are dominated by the indirect travel time savings, which are much lower than the direct travel time savings. On the other hand, the fraction of Metro users is approximately 40% of the total population, so the direct travel time savings are much more evident. Furthermore, the dominant indirect travel time savings are higher for Metro than for Metrobús, increasing this difference even more.

Other literature generally finds higher values for travel time savings, especially in comparison with Metrobús. Instituto Nacional de Ecología (2006) studied the first Metrobús corridor and found travel time savings of 29.1%, which is much higher than the travel time savings found in this research. However, Instituto Nacional de Ecología (2006) only takes into account direct travel time savings. Hence, the Metrobús line four direct travel time savings are a little higher than those found for the first corridor. For other studies, travel time savings range from 1.7% to 42%, averaging at 26.4% (Blonn et al., 2006; Breakthrough Technologies Institute, 2012; Deng and Nelson, 2013; Felipe Ochoa y Asociados, 2012; Instituto Nacional de Ecología, 2006; Levinson et al., 2003; PROPOLIS, 2004; Turner et al., 2012; Vincent and Callaghan, 2007). However, since most of these studies only take into account direct travel time savings, a comparison with this study's travel time savings for the entire population is not justified. However, a comparison with the direct travel time savings is possible. This shows that the Metrobús line performs almost as good as the study with the highest travel time savings. Furthermore, the Metro line performs somewhat better than the average. Despite the focus of literature on direct travel time savings, it is nevertheless recommended to use the total travel time savings for future studies, because this provides a better insight in the impact of the transit line on transport in the zone of influence. This is illustrated by this study, because focusing on direct travel time savings suggests that the Metrobús line performs better, while overall travel time savings, and thus transport system impacts, are higher for Metro.

A more detailed look at the travel time savings shows some relevant observations. First of all, the average travel time savings per trip are much higher for Metro than Metrobús. Furthermore, the annual travel time savings are much higher for Metro than Metrobús. This is partially due to the higher travel time savings per trip and partially because the total number of trip is higher for Metro than Metrobús. Secondly, the monetized travel time savings using an income-dependent VOT show that for both transit lines the majority of these savings correspond to the second and third income groups, which also represent the majority of the trips. Nevertheless, the travel time savings for these two groups embody a smaller fraction of the total than the trips. This indicates that the higher income groups are overrepresented in the monetized travel time savings, given their contribution to non-monetized travel time savings and the total number of trips.

For the Metrobús travel time savings were not included in the ex-ante appraisal. However, the Metrobús visit revealed that they think travel time savings are around 50%. In reality, this is much lower for the total travel time savings and even somewhat lower for the direct travel time savings only. For the Metro line, Spectron Desarrollo (2009) estimated total monetized travel time savings at US$ 326.1 million per year. Hence, the actual monetized travel time savings found in this study are 24.8% higher than the estimation made beforehand. This is due to a higher number of daily users than previously estimated and a higher VOT used in this study, which is discussed elaborately in the sensitivity analysis (section 7.3.1).

If only direct travel time savings are taken into account, some interesting remarks can be made. First of all, the travel time savings are higher for Metrobús than Metro. However, the average travel time savings in minutes are higher for Metro than Metrobús. This suggests that the travel times in Metro are significantly higher for Metro than Metrobús. In fact, average Metro travel times are more than double those of Metrobús (97.5 minutes vs. 47.7 minutes). Second of all, the number of daily trips is much higher for Metro than Metrobús. Consequently, and because travel times are higher, the total direct travel time savings are much higher for Metro than Metrobús.

Hence, for the former the direct travel time savings have a much more significant impact on time spent in transport for the entire MCMA. Third of all, these travel time savings are distributed more evenly over the income groups for Metrobús than for Metro. Subsequently, if an income-dependent VOT is used the average monetized travel time savings per trip are higher for Metrobús than Metro, even though the temporal travel time savings per trip are higher for Metro. Fourthly, the total monetized travel time savings, using an income-dependent VOT, are higher for Metro than Metrobús. However, this difference is smaller than for the actual travel time savings. For Metrobús, the majority of these monetized savings are the result of travel time savings for the fourth and sixth income group (30.0% and 26.3%), while these income groups only represent 21.1% and 5.6% of the travel time savings, respectively. For the Metro line the second and third income groups are contributing most for the monetized savings (31.2% and 34.9%) and represent 44.8% and 25.0% of the travel time savings. Hence, for the Metrobús a minority of users represent a majority of monetized travel time savings, while for the Metro this is not the case. Fifth and finally, if the equity VOT is used instead of income-dependent VOT, the monetized travel time savings are much higher and the difference between Metro and Metrobús is much larger, which is logical considering the average income of users, which is considerably lower for Metro than Metrobús. Another interesting difference is that these monetized travel time savings represent a vast majority of total monetized travel time savings for Metro, but a minority for Metrobús. This, once again, is the result of the fraction of users of the total population, which is higher for Metro.

The relative change in indirect travel time savings is higher for Metro than Metrobús, as well as the average travel time savings per trip. Furthermore, the total annual indirect travel time savings are higher for Metro than Metrobús. This is partially due to the higher average travel time savings, but also because the number of non-user trips is higher for Metro than Metrobús. However, this difference is much smaller than for the direct travel time savings. Additionally, the distribution of travel time savings over income groups shows that this is spread more equally for Metro than for Metrobús, for which travel time savings are mainly experienced by the second and third income group. As a result, the average monetized travel time savings, using an income-dependent VOT, are higher for Metro than Metrobús. These savings are significantly smaller than for the direct savings. Also if an income-dependent VOT is applied the total annual monetized indirect travel time savings are higher for Metro than Metrobús. For Metrobús, 93.3% of these monetized savings are attributable to the second and third income groups, while for Metro the third and fourth group are the largest contributors (28.7% and 31.7%). Meanwhile, these represent the majority of travel time savings for Metrobús (96.9%), but only 43.1% of indirect travel time savings for Metro. Hence, a minority of Metro non-users embodies the majority of monetized travel time savings. Finally, application of the equity VOT shows that annual monetized indirect travel time savings are higher for Metro than Metrobús, although they represent 32.0% and 73.1% of total monetized travel time savings, respectively.

7.1.3.2 CONSTRUCTION COSTS

Construction costs differ greatly between the Metrobús and Metro line; almost forty-five times higher for the latter. This difference was anticipated, because MRT systems are generally more expensive than BRT systems, especially due to higher infrastructure construction costs and more expensive vehicles. Compared with other BRT systems, the Metrobús construction costs are very low. These average at US$ 6.7 million (see section 5.5.2) and of all the literature studied only the BRT system in Jakarta (Hidalgo and Gutiérrez, 2013) and Runcorn, UK (Levinson et al., 2003) have lower construction costs per kilometer than the Metrobús line. An explanation for this difference is that some of these BRTs are located in economically more prosperous countries, such as the U.S.A. and Australia. Such countries have higher labor costs, increasing the cost of construction considerably. Secondly, the Metrobús corridor studied has low construction costs because it is not a full BRT line. Especially the limited number of stations decreases construction costs. For example, the construction costs of Bogotá's TransMilenio, which is one of the most complete BRT systems in the world, are much higher at US$ 12.5 million per kilometer (Hidalgo and Gutiérrez, 2013). Interestingly, Hidalgo and Gutiérrez (2013) also find that construction costs for other Metrobús corridors, which do have stations for each stop, are higher at US$ 2.8 million per kilometer. Hence, the simplicity of the Metrobús line's design clearly reduced construction costs. The ex-ante cost-benefit analysis estimated construction costs for the line to amount to almost US$ 32 million (SOBSE, 2011). However, actual construction costs of the Metrobús line are around US$ nine million, or 29.2%, higher than planned. Relatively, this is a considerable budget overrun, though in absolute term this is not very high.

For MRT systems, the average construction costs of other projects are US$ 87.5 million per kilometer. Hence, the constructions costs of the Metro line are considerably lower. However, of all the MRT systems studied, almost all the systems with higher construction costs per kilometer are located in Europe, the U.S.A. or Australia. The only two exceptions are the MRT of Caracas and Santiago (Flyvbjerg et al., 2008). Hence, similarly as for the Metrobús, it would be expected that construction costs for those lines are higher due to higher labor costs, among others. Hence, it seems the Metro line is relatively expensive. This is confirmed by the construction costs of the previous Metro line implemented in Mexico City (line B), which cost only US$ 43.8 million per kilometer (Flyvbjerg et al., 2008) and thus line twelve was 40.1% more expensive. On the other hand, line B was implemented in 1999 and inflation since then was higher than 40.1%, suggesting lower construction costs for the twelfth Metro line. Spectron Desarrollo (2009) estimated the construction costs of line twelve in an ex-ante appraisal at a total of US$ 1.9 billion implying that actual construction costs turned out 13.7% lower than estimated beforehand. This means a considerable budget saving of US$ 0.3 billion was made.

7.1.3.3 OPERATING AND MAINTENANCE COSTS

The operating and maintenance costs are highest for the Metro line, as was shown in the previous chapter. This difference was expected, because the operating and maintenance costs of rail infrastructure are generally much higher than the cost of BRT systems. Furthermore, the Metrobús line has mainly stops instead of stations, so less maintenance is required. As was already mentioned several times in this discussion chapter, the main explanation for difference in performance between the systems is the number of passengers. Therefore, it is interesting to study the operating and maintenance costs per passenger. For Metrobús, this is 3.78 pesos per passenger, while for Metro this amounts to 4.04 pesos per passenger. Hence, in these terms, the systems are very alike, even though operating and maintenance costs per passenger are higher for Metro. Furthermore, this indicates that for both systems the ticket fare is higher than the operating and maintenance costs per passenger, indicating that the line operation is financially profitable. However, it is important to note that this does not incorporate overhead costs of the administrative personnel. For the Metrobús, these overhead costs are paid for by the government of the Federal District, which is an indirect subsidy to the Metrobús system. For the Metro, the subsidy per ticket is around 7.5 pesos. This deficit can partially be explained by the overhead costs and a possible lower profitability of other Metro lines, but this calculation probably also includes costs for interests on loans required for construction costs. Hence, even though operating and maintenance costs are lower than ticket fares, subsidies are still required due to cover other costs of the systems.

As the flags already suggest, compared to other studies the operating and maintenance costs are very low for Metrobús and very high for Metro. In fact, of all the studies that included operating and maintenance costs and corridor length, none had higher costs than the Metro and none had lower costs than the Metrobús (Blonn et al., 2006; Devillers et al., 2011; Felipe Ochoa y Asociados, 2012; Madison Area Transportation Planning Board, 2013; Spectron Desarrollo, 2009). However, in terms of magnitude these costs are more in line with the Metro costs than the Metrobús costs, since they are all over US$ 0.9 million per kilometer. Hence, the operating and maintenance costs for the Metrobús are extremely low, while the Metro costs are high, but not irrational. However, most of these studies are for MRT systems, which also partially causes this difference.

The ex-ante appraisal by SOBSE (2011) estimated a total discounted operating and maintenance cost for the Metrobús line of US$ 3.1 million for the project horizon of ten years. The discounted NPV of the first ten years of Metrobús operation that are calculated for this study amount to 26.4 million US$. This is more than eight times as high as the estimation in the ex-ante appraisal. Hence, operating and maintenance costs are significantly higher than the costs estimated in advance. For the Metro line Spectron Desarrollo (2009) estimated total operating and maintenance costs at US$ 48.2 million per year. However, actual operating and maintenance costs are US$ 42.5 million per year. Hence, these costs are approximately 12% lower than estimated beforehand, indicating a significant cost saving.

7.1.3.4 REVENUES

The revenues are significantly higher for Metro than Metrobús, as the previous chapter revealed. The main difference between the two systems is the daily ridership, which is almost ten times higher for Metro than Metrobús. This explains the higher revenues for the Metro line. Meanwhile, the ticket price is a little higher for Metrobús, but this line is also longer, so these characteristics more or less cancel each other out. Other studies show that revenues average at US$ 1.1 million per kilometer (ALC-BRT and EMBARQ, 2013; Blonn et al., 2006; Devillers et al., 2011), indicating that the Metro revenues are high and Metrobús revenues very low. The available data does not show a relationship between the standard fare and the revenues per kilometer. Hence, it seems that other indicators, such as system capacity, are more influential on the revenues. However, the most important relation is with the operating and maintenance costs, as this indicates the financial cash flow resulting from the operation of the line. This is discussed in section 7.2.2.1.

The estimated annual revenues for Metrobús line four were US$ 10.4 million (SOBSE, 2011). Hence, the actual annual revenues are approximately 28% lower. However, if the data in the CBA is used to calculate the revenues a different outcome is found (multiplication of annual passengers and ticket price). Hence, the revenues are calculated incorrectly. As a result, the estimated annual revenues are only US$ 4.9 million. This suggests that actual revenues are around 53% higher than anticipated. Since the current number of passengers is higher than the estimated demand, this is plausible. For the Metro, Spectron Desarrollo (2009) does not include operating revenues in the ex-ante appraisal. However, there are two reasons to assume that actual revenues are higher than anticipated during implementation. First of all, the number of daily passengers is higher than was estimated in the ex-ante appraisal. Secondly, the recent 67% ticket fare increase, that was elaborated on in section 4.3, suggests that the total revenues are higher than could have been expected during implementation.

7.2 AGGREGATED INDICATORS

This section discusses the indicators in aggregated form. First of all, the indicator aggregation using the flag model is addressed. This concerns both the composite social, environmental and economic indicators and the overall aggregation. Secondly, the results of the other aggregation methods are discussed. This involves the economic performance of the economic indicators expressed in terms of the NPV and B/C ratio and the efficiency of the indicators, both economically and per user trip.

7.2.1 FLAG MODEL

In terms of social indicators, both transit lines perform similarly, but the Metro performs a little better. The individual indicators show that the Metro performs better on both indicators, although the standardized value for the equity indicator is equal, because this is the maximum value. In terms of safety the Metro also performs better. Hence, it is logical that the Metro line performs better on the aggregated social indicator.

Both corridors perform very similarly in terms of environmental indicators, although the Metrobús performs somewhat better. Interestingly, the Metro line performs significantly better on two of the three indicators (air pollution and climate change). However, the standardized performance difference for modal shift is so large that it compensates the other two indicators. It is important to note that this difference is mainly caused by the CTVs, because the Metro performs more than twice as good in terms of emission reduction on both air pollution and climate change. Meanwhile, the Metrobús does not perform twice as good in terms of modal shift. Nonetheless, the small range in CTVs for modal shift and large range for air pollution and climate change causes a larger difference in standardized values for modal shift than the other indicators. This is considered a clear disadvantage of using CTVs based on literature values.

The Metrobús also performs better for the economic aggregation. The Metrobús performs better on two of the four indicators, which would suggest that both systems perform similarly. However, the difference in standardized value is largest for the operating and maintenance costs indicator, with the minimum value for Metro and the maximum value for Metrobús. Hence, the effects of this indicator are most dominant in the aggregated outcome of the economic indicators. Remarkably, the difference between revenues and operating and maintenance costs is higher for Metro than Metrobús, but if the standardized values are averaged the latter performs better. This indicates the disadvantage of using CTVs based on literature values once more.

The overall standardized value is based on the average of the standardized values of the three composite indicators. This standardized value indicates that the Metrobús performs slightly better than the Metro, although the difference is very small. This is remarkable, since the Metro performs better on six of the nine indicators. Both corridors are attributed a red flag, indicating low to medium overall performance. However, the values are very close to zero, indicating that the performance is closer to medium than to low. Furthermore, this means that the outcomes of this research are close to the average values found in literature. Hence, the results found in this study are feasible. Additionally, although both lines are given a red flag, this performance is high, because many of the values used in literature are for user benefits only, while this study also incorporates indirect effects. As the discussion of individual indicators already mentioned, the direct impacts are significantly larger than the indirect impacts. Hence, if only direct effects were included, the outcomes would definitely be above the average values found in literature. The application of the flag model for direct effects only is discussed more comprehensively in section 7.3.2.

It is important to note that in terms of the three dimensions of sustainability, this study pays more attention to the economic and environmental indicators than to social indicators, given the number of indicators. Hence, the impact of one social indicator on the overall outcome is much higher than the impact of one environmental or economic indicator. This means that inaccuracies in the evaluation of social impacts influence outcomes more significantly than inaccuracies in the other two dimensions. This also implies that the conclusions on environmental and especially economic impacts are more solid. Nonetheless, the aggregated evaluation provides interesting insights, because often social, but also environmental, indicators are excluded from the evaluation since evaluation is difficult. This means that such impacts are completely excluded from the outcomes of transport projects evaluations. Thus, this study provides an important improvement in that respect.

7.2.2 OTHER AGGREGATION METHODS

This section discusses the other aggregation methods that have been applied. First of all, the economic performance of both systems is addressed. This focuses on the economic indicators that were aggregated using more conventional aggregation methods, such as the NPV and B/C ratio. Secondly, the economic efficiency is addressed, which is a comparison between the indicators in terms of the magnitude of effects per invested dollar. Finally, the efficiency of impacts per passenger is elaborated on.

7.2.2.1 ECONOMIC PERFORMANCE

The NPV for both transit lines was presented in the previous chapter. This showed that the NPV is almost three times higher for the Metro than Metrobús. Both systems have a small operating profit (difference between revenues and operating and maintenance costs) and construction costs are much higher for Metro than Metrobús. Hence, the main difference in NPV is due to the difference in monetized travel time savings. However, if an income-dependent value of time is used, the NPV is negative for the Metro, but still positive for the Metrobús. This shows that the NPV of the Metro is more dependent of the travel time savings than the NPV of the Metrobús. The NPV of the construction costs, operating and maintenance costs and revenues is only US$ -25.4 million for Metrobús, but US$ -1.6 billion for Metro. This shows that the travel time savings are much more influential on the profitability of the project for Metro than Metrobús. Furthermore, this indicates that significant impacts must be acquired for the Metro in order for the project to be profitable. However, only a limited number of benefits is included in the economic aggregation. Thus, the economic benefits are underestimated, because other economic benefits such as health benefits due to reduced air pollution and accident reduction benefits are not monetized in this evaluation. As a result, the actual profitability of both projects is higher than the numbers presented in this study. Nevertheless, travel time savings often constitute the majority of economic benefits, so this study gives a good indication. Furthermore, despite this underestimation both projects are profitable.

The Metrobús visit showed that no subsidy is required for the operation of Metrobús. The results of this study confirm that. However, this does not include the overhead costs of the Metrobús organization, which is paid for by the government. Hence, this is indirectly a subsidy to the Metrobús system. For the Metro, STC (2013c) claims that for every ticket a subsidy of 7.5 pesos (US$ 0.57) is contributed. Given the lower income of the Metro users, the subsidy is mostly enjoyed by low-income groups. Furthermore, the flat fare structure and concessionary fares for elderly and handicapped especially aid lower incomes, and can therefore be regarded as a form of subsidy (Serebrisky et al., 2009). However, the revenues and operating and maintenance costs represented in this study suggest that line twelve is profitable. Hence, it seems that this subsidy is mainly due to lower profitability of other Metro lines. Furthermore, the interview with Emelina Nava revealed that the organization of the Metro is much larger and more bureaucratic than Metrobús. This means that overhead costs of the Metro are significantly larger. Additionally, many of the protestors against the fare increase claimed high corruption, which was confirmed by Emelina Nava, although not specifically for the Metro, but for Mexico City in general. Hence, it seems that for both lines the passengers pay for the operation of the line, but that the organization of the systems is paid for by the government. The construction costs are also paid for by the local government.

Meanwhile, the benefits are largely enjoyed by the users, as they experience the travel time savings, especially for the Metro. However, many other travelers also receive indirect benefits, but they do not pay for the operation of the lines through fares. On the other hand, they indirectly pay for the construction of the line through taxes. For the Metrobús, both direct and indirect travel time benefits are higher than the construction costs, while for Metro only the direct travel time benefits are higher. Hence, for the Metrobús the users pay approximately 65% of the construction, operating and maintenance costs through ticket sales, while for the Metro users pay only more or less 17% of those costs. Hence, for the Metrobús the users pay the majority of costs, while they only receive 27% of the benefits. This means that especially other travelers benefit from the implementation, even though they pay a minority of the costs indirectly through taxes. Contrarily, for the Metro the users only pay for a small part of the costs, but enjoy 68% of the benefits. This means that the main beneficiaries of the implementation only pay a small fraction of the costs. Thus, the majority is paid for by the tax payers of the Federal District, while most of them do not benefit directly or indirectly from the implementation.

The ex-ante appraisal of the Metro line shows that a NPV of US$ 86 million was anticipated, resulting from a NPV of total costs of US$ 2.49 billion and a NPV of total benefits of US$ 2.58 billion (Spectron Desarrollo, 2009). Hence, the NPV found in this study is significantly higher. This is partially due to a higher NPV of all benefits, which amounts to US$ 3.33 billion, and a lower NPV of all costs, which is US$ 1.88 billion in total. This difference is partially explained due to the lower travel time savings found in the ex-ante appraisal and the exclusion of revenues in that analysis. Additionally, the construction costs and operating and maintenance costs are lower in this ex-post evaluation. On the other hand, the CBA is stretched over a longer time period. However, because benefits and costs are discounted, the additional years do not contribute significantly to the NPV. The ex-ante appraisal of the Metrobús finds a NPV of US$ 42 million (SOBSE, 2011). This is much lower than the NPV found in this ex-post evaluation. However, the ex-ante appraisal does not include travel time savings, which constitute the main benefits of the ex-post evaluation. Hence, making a meaningful comparison with this ex-ante evaluation is difficult.

The discount rate and the project horizon are two important specifications set for this evaluation. These values significantly influence the economic performance of both systems. Due to the discount rate of 12% the travel time savings in the first year are almost four times larger than the savings in the last year. For the revenues and operating maintenance costs this is almost six times, because no correction for GDP growth is applied. Hence, the discount rate significantly affects the economic performance. Since the same value is used in many other studies in Mexico, this value seems useful. The project horizon of fifteen years also seems correctly chosen, because the monetary impacts in the final years are small. Thus, extending the project horizon would not significantly influence the economic performance. Therefore, the current project horizon is considered adequate for this research. However, it can be argued that the lifespan of an MRT system is considerably longer than the lifespan of a BRT system. Hence, it may be more appropriate to apply a longer project horizon to evaluate the Metro than the Metrobús. Alternatively, the residual value after project horizon can be used to compensate for this difference in lifespan. This consists of, among others, remaining infrastructure, stations and vehicles. Parra Alva (2007), for example, applies a residual value of 20% of the initial construction costs. For the two transit lines studied in this research, that would result in a residual value of US$ 8.2 million for the Metrobús and US$ 323 million for the Metro. This means the NPV would increase, after discounting, by US$ 1.2 million and US$ 47 million, respectively.

Another issue with the inclusion of future impacts in this evaluation is that the evaluation assumes that impacts remain equal over the years, while in reality this may not be the case. For example, due to reduced congestion from the implementation of the transport project travel time savings are realized. However, this reduced congestion may result in latent demand, which in turn manifests in more congestion and higher travel times, nullifying part of the acquired benefits. This particularly affects the indirect impacts, which are more sensitive to supply and demand (since infrastructure is public unlike the project's rail infrastructure and segregated bus lanes). Hence, extrapolating current travel time savings over a fifteen year evaluation period may overestimate the travel time, and thereby total, impacts. This especially holds for the Metrobús, which is much more dependent on indirect impacts than the Metro. On the other hand, the question remains what would have happened if no mass transit corridor were implemented, because in that case traffic would increase as well due to natural growth. Given the already existing congestion problems, this could increase travel times as well. Hence, comparison with the reference scenario, which this study does not, would nullify at least part of the overestimation of travel time savings. Furthermore, the high discount rate means that later impacts only represent a small fraction of total impacts. Nonetheless, this does leave some inaccuracy in the estimation of the economic performance.

7.2.2.2 ECONOMIC EFFICIENCY

The B/C ratio shows the economic efficiency of the investment. This B/C ratio is almost five times higher for the Metrobús than the Metro. This indicates that each dollar invested in the project yields significantly higher monetary benefits for the Metrobús line than the Metro line. This implies that if benefits are desired with minimal investments, it is preferable to implement a BRT. However, it is important to note that a system mimicking the fourth Metrobús line will never be able to attain a capacity comparable to the Metro, so nonmonetary impacts are likely to be smaller, as this evaluation also shows. Furthermore, a more detailed study of the results shows that the Metrobús line is profitable within the first year after operation (second year for income-dependent VOT). The Metro line only becomes profitable after six years of operation (never for income-dependent VOT). This shows that for both projects the payback period is only a few years.

Section 6.5.3 presented the economic efficiency per indicator for the social and environmental indicators. This shows that the Metrobús is more efficient for all indicators, although the magnitude differs between indicators. The main reason for this difference is the lower construction costs. In terms of absolute impacts, the Metro performs better for all indicators, but the Metrobús offers such large advantages in terms of construction costs, that these result in higher economic efficiency. The economic efficiency for the indicators is discussed from the largest difference to the smallest difference. The difference in economic efficiency is largest for the equity indicator. This is logical, because this is the only indicator for which the population size does not influence the magnitude of the results, as the Gini-index is determined for the entire population. Hence, this difference mainly represents the difference in construction costs and not the economic efficiency to improve equity. However, the Metro equity improvement is experienced by a larger population, which means that its equity effects are experienced by more travelers, but this is not expressed in the equity economic efficiency.

Subsequently, the safety indicator portrays the largest difference. For this indicator, the total points in difference (for the entire population) are divided by construction costs. The individual indicator discussion already showed that the differences between Metro and Metrobús were small, so if this is divided by the construction costs, it is coherent that economic efficiency is much higher for Metrobús. Next, the modal shift shows a large difference between Metrobús and Metro. This only concerns the user population, so is more favorable for the Metro. However, the results show that the modal shift in relative terms is almost eight times as high for Metrobús. Even though the absolute number of travelers shifting from private modes is higher for Metro, the economic efficiency of Metrobús is still much higher due to the significantly lower construction costs.

The three pollutant emissions that constitute the air pollution indicator portray a smaller difference between Metro and Metrobús in terms of economic efficiency. Especially PM_{10} emissions are very similar, but also NO_x and CO emissions perform considerably well for Metro. The CO_2 emissions indicating climate change show an even smaller difference between Metrobús and Metro efficiency. Nonetheless, the Metrobús is still more efficient. The main reason for this difference is that these avoided emissions only result from the user modal shift. Hence, the population is almost ten times larger for the Metro. This makes the absolute impacts more significant and improves the economic efficiency. Furthermore, these indicators are economically more efficient than the modal shift indicator, because the total modal shift is incorporated (and not only the modal shift from private vehicles), which environmentally is more beneficial for Metro. Hence, in terms of economic efficiency the Metro system is most preferable to reduce emissions, although the Metrobús is still more efficient in this respect.

The economic efficiency of the travel time savings was determined in a slightly different way. The total discounted monetized travel time savings for the entire evaluation period were divided by the construction costs. The results show that for travel time savings the Metrobús is much more economically efficient than the Metro. Furthermore, it is interesting to note that the majority of the efficiency results from commute trips. This is not surprising, since the trip purpose ‘work’ represents more than half of all trips. This implies that investments that target improvements during commuting times, which coincides with peak hours as well, have most significant travel time saving impacts. In is therefore recommended to focus transport planning on the most critical corridors during commuting times, because this yields the highest travel time benefits. Besides such infrastructure improvements, it is also useful to adjust the capacity of a mass transit line according to the demand. For example, additional vehicles can be operated during peak hours so frequencies and capacity are higher and the number of passengers increases. During off-peak hours frequencies can be lower, because demand is lower as well. This way, the operation of the system is more efficient and profitability increases.

7.2.2.3 TRIP EFFICIENCY

The efficiency per user trip shows very different results. In terms of construction costs and travel time savings, the Metrobús line is more efficient. Especially the construction costs per trip are much (more than four times) lower for the Metrobús. However, this difference is smaller than the difference in construction costs per kilometer. This shows that although the construction costs of the Metro are higher, the higher capacity of the line means that more passengers are served, which improves the efficiency. Nonetheless, the total construction and operating and maintenance costs per trip are US$ 0.96, compared to a ticket price of US$ 0.38. For the Metrobús the total costs per trip are US$ 0.45, compared to a ticket price of US$ 0.46. This means that the costs are more or less paid for by the passengers, although in reality the discounting results in lower revenues per passenger. Hence, in terms of efficiency, the economic model of the Metrobús is more solid. This difference is mainly due to the difference in construction costs, because operating and maintenance costs per trip are almost equal.

The efficiency of travel time savings is also higher for the Metrobús than the Metro. However, the results of the travel time savings suggest that average direct travel time savings are higher for Metro than Metrobús. This is because the travel time savings efficiency is based on the total travel time savings divided by the number of user trips, while the average direct travel time savings are calculated by dividing the direct travel time savings by the number of user trips. Hence, the main reason for the difference is that the indirect travel time savings per user trip are significantly higher for the Metrobús than the Metro. Once again, this can be explained by the much lower fraction of users of the entire population for the Metrobús. This implies that even though the total travel time savings are lower for the Metrobús, each Metrobús passenger has a relatively more significant impact on other road transport than each Metro passenger. Thus, each passenger contributes more to reducing congestion and improving travel speeds on roads within the zone of influence. Given the higher modal shift from private vehicles, this conclusion is probable, because the Metrobús line has a relatively higher impact on the number of vehicles on the road.

In terms of emission reductions the Metro is more efficient than Metrobús for all different gases, but particularly PM_{10} and CO_2. This means that the average emissions avoided due to the modal shift are higher for the Metro than the Metrobús. This was expected, because the relative emission reductions are also higher for the Metro than the Metrobús. The main explanation for this is the difference in the modal shift. Although the modal shift from private vehicles is higher for the Metrobús, the modal shift from low-capacity public transport is higher for Metro. Furthermore, a large part of the Metrobús modal shift origins from the Metro, thereby actually increasing the total emissions. Additionally, the Metrobús also causes some emissions itself, unlike the Metro. Hence, it is logical that the emission reduction per trip is higher for Metro than Metrobús.

7.3 SENSITIVITY ANALYSIS

This section discusses the sensitivity analysis for which the results were presented in section 6.6. First, the sensitivity of several indicators is elaborated on. Secondly, the sensitivity of the flag model is addressed.

7.3.1 INDICATOR SENSITIVITY

A sensitivity analysis was conducted to show the effects of some of the assumptions made for the parameters. The influence of the value of time on the NPV and B/C ratio was investigated by varying the VOT. This shows that varying the VOT results in large differences in the NPV and B/C ratio. Especially for Metro, the effect of changing the VOT results in major changes in the NPV. As section 6.4.1 discusses, the Metro travel time savings are significantly higher than those of Metrobús. This explains why changing the VOT has more impact on the Metro NPV than the Metrobús NPV. However, changes in B/C ratio are more significant for Metrobús than Metro. This can be explained by the lower costs for the Metrobús. Hence, a similar change in the benefits for Metro and Metrobús results in a higher change in B/C ratio for Metrobús. Since the total discounted costs are over thirty times higher for the Metro, this effect is very significant.

These variations in NPV and B/C ratio due to different VOTs are significant for the research, because it indicates that especially the economic performance of the Metro is very sensitive to variations in the VOT. This makes it difficult to determine which project is in fact more profitable. Nonetheless, the results do indicate that the Metrobús line is certainly profitable, while for the Metro line this is very dependent on the VOT. In order to give some perspective on the VOTs used in this sensitivity analysis a comparison is made with VOTs used in other studies. Spectron Desarrollo (2009) uses a value of time based on 100% of the average income of users, which is US$ 2.74 per hour. Felipe Ochoa y Asociados (2012) uses a lower value of US$ 1.73 per hour, while Parra Alva (2007) uses a VOT of US$ 0.63 per hour and Instituto Nacional de Ecología (2006) applies a VOT of only US$ 0.48 per hour. Studies in other countries show even more variance, but if these are corrected for GDP per capita based on data from World Bank (2014) these allow for comparison. Hidalgo et al. (2013) and Blonn et al. (2006) use a corrected VOT of US$ 1.57 per hour and US$ 1.48 per hour, respectively. Eijgenraam et al. (2000) suggest a VOT of US$ 4.14 per hour, which is more or less equal to the VOT used in this study. Hence, great variability in VOT exists within studies for Mexico, but also in a more international context. On average, the VOT of these studies is US$ 1.92 per hour. Compared to the values used in this sensitivity analysis, this equals the VOT of 25% of the average income or the income-dependent VOT using 100% of the income. However, a VOT of 50% of the income is regarded more realistic.

Furthermore, the results show that if income-dependent VOTs are used, high-income groups represent a disproportionally large percentage of monetized travel time savings compared to the non-monetized travel time savings. Consequently, travel time impacts for high-income groups become relatively more important than travel time impacts for low-income groups. For example, for the Metrobús the sixth income group represents a negligible 1.6% of travel time savings, but a significant 10.9% of monetized travel time savings. From an egalitarian perspective, assuming that everyone is equal, this is undesirable. Given the great social disparities in Mexico, that are elaborated on in chapter four, it is objectionable that a small high-income group influences the outcomes so significantly. Thus, using an equity VOT is recommended. However, the VOT of 50% of the average income is high compared to the values found in literature. Furthermore, a median income better represents the population, because unlike the average income, this is not dominated by a small high-income group. A VOT based on 50% of the median income is closest to the values found in literature. For this VOT the Metro line is economically more profitable.

Despite the uncertainty in economic profitability, the comparison made for the travel time savings and the aggregated indicators using the flag model is significant, because these encompass relative change. This relative change is uninfluenced by the VOT, because a higher VOT only increases absolute monetized travel time savings and not the relative change in monetized travel time savings. Hence, the VOT only influences the absolute travel time savings and the economic performance. Furthermore, in terms of economic efficiency the Metrobús line performs better for every VOT. Thus, economically the Metrobús line is definitely more efficient.

For the emission factors three scenarios were developed. The results show especially significant impacts on the absolute change, while differences in relative change are small. This makes sense, because a change in emission factors results in a change of previous emissions as well as current emissions. Hence, both the numerator and denominator increase or decrease, resulting in only a small difference in terms of relative change. However, in absolute terms the changes are significant. For example, the doubling of emission factors for public road transport results in significantly higher absolute emission reductions, because the total emission levels are much higher. This means that although the values of emission factors do have an impact on the absolute emission reductions, this impact is marginal for the relative change. Consequently, the results of this evaluation are only marginally influenced by the values of the emission factors. However, this also suggests that the modal shift is the main determinant of the impacts on emissions. This means that all three indicators demonstrate more or less the same effect. The only difference between climate change and air pollution effects on the one hand and modal shift impacts on the other hand is that the ratio between users and non-users is more important for the former than the latter. This is also the reason why the Metrobús performs better on environmental indicators than the Metro.

In relation to the scenarios developed, some observations are made as well. First of all, the Metro scenario shows expected results, since emission reductions increase for the Metrobús, and decrease for the Metro. However, the relative change of air pollution decreases for Metrobús, because of the larger denominator. The public transport scenario results in higher absolute and relative emission reductions. This is logical, since for both a large part of the modal shift results from public road transport. Hence, higher emission factors for those modes result in higher emission reductions. The private transport scenario reduces absolute emissions reductions. However, relative emission reductions increase, except for climate change emissions for Metrobús. This increase in relative change is due to a decrease in the denominator, making the emission reductions of the other transport modes more significant.

The sensitivity analysis of the equity indicator shows that, especially for Metrobús, the relative improvement differs significantly if different social characteristics are used to measure equity. However, the absolute values of the Gini-indices are very similar if age or education is used instead of income. Hence, the main reason for the large differences in relative change is because the Gini-indices are close to zero. Therefore, the equity indicator is extremely sensitive to a minimal change in the Gini-index. This means that if the situation becomes only slightly more equal, the relative equity improvement is very high. If the equality in distribution of travel times, regardless of income group, is analyzed, several differences occur. First of all, the relative improvements are much lower, and closer to the values found in literature. Secondly, the absolute value of the Gini-index is much higher, since larger differences exist between the minimum and maximum travel time than between the average travel times per income group (which the standard equity indicator basically applies). The value of the Gini-index is very similar to the income Gini-index for the Federal District. The main difference with the standard approach in this thesis is that this Gini-index does not indicate who actually benefits most from the travel time savings, only that the distribution of travel time savings is more equal. Hence, the distribution of travel times may be more equal, but meanwhile mainly high-income groups benefit from the travel time savings. Thus, this only measures equality effects and not equity impacts, because an equity analysis includes moral judgment of the fairness of impacts. Hence, equity presumes that ideally low-income groups benefit more from the travel time savings than high-income groups. Consequently, this Gini-index does not incorporate a judgment on the fairness of the distribution. Concluding, both ways to estimate the equity improvement have their advantages and disadvantages. However, it is considered most important that some form of moral judgment is incorporated in the equity indicator. This outweighs the disadvantage of the high sensitivity.

7.3.2 FLAG MODEL SENSITIVITY

The application of the flag model to exclusively the direct effects yields very different results. The only indicators that are affected by this are travel time savings, equity and safety. For the Metro this results in a significant improvement of all three indicators, while for the Metrobús only equity performs worse and the other two indicators' performance improves significantly. For the travel time savings and safety indicators, the improvement is largest for Metrobús. This was expected, because the direct effects of both systems are more or less equal, but large differences in direct impacts result from the fraction of users. This fraction is much lower for the Metrobús, which means that indirect effects have a more significant influence on the total impacts than the direct effects. This effect was already discussed elaborately in section 7.1.3.1, but this sensitivity analysis confirms that this is the case. For the equity indicator, the difference is more difficult to determine because here the magnitude of effects does not influence the impacts. Hence, the distribution of travel time savings differs significantly for users and other travelers. The former experience more equity benefits from the Metro, while the latter are favored more by the Metrobús.

The effects of these changes in indicator values on the attributed flags and standardized values are also significant. For the Metrobús, one flag changes from black to green (travel time savings), one flag changes from red to green (safety) and one flag remains green (equity). Meanwhile, standardized values of the three indicators increase on average by 1.5 points. For the Metro, one flag changes from red to orange (travel time savings) and two flags remain green (safety and equity). The standardized values on average increase by 0.9 points. This illustrates, once again, that the changes are largest for the Metrobús. The aggregate flags also improve, and their standardized values also increase, except for the environmental dimension, which is unaffected by this sensitivity analysis. Interestingly, both transit lines now perform above the average performance, compared to other mass transit systems.

This sensitivity analysis shows that the standardized outcomes are sensitive to changes in the indicator values. The flags and standardized values resulting from this analysis are more realistic, because most of the literature used to determine the CTVs only incorporates the direct effects. Hence, in the standard analysis incorporating total effects, the flag colors and standardized values are underestimated. This is considered a limitation of this research, because the flag model does not accurately evaluate the indicators this way. Nonetheless, it does provide a useful tool to compare both systems. Since the same CTVs are applied to both systems, the difference in flag colors and standardized values does accurately represent the differences between the two lines. Hence, for comparative purposes the flag model is very useful. An important advantage of including indirect effects is that this better represents the effects on transport in the city, since the number of passengers is of great importance for the impacts on the transport system in general. Hence, this indirectly includes the magnitude of the absolute impacts in the framework, because otherwise only relative changes are included (except for most economic indicators and the modal shift). On the other hand, for indirect impacts it is more difficult to ascertain that observed impacts are in fact endogenous. Hence, it remains ambiguous if the estimation of indirect impacts in this study are in fact attributable to the project. Most likely, some impacts are caused by other developments, such as changing land use patterns. Alternatively, it can be argued that impacts may be more widespread than the immediate vicinity of the corridor, because travel patterns change due to reduced congestion. In that case, indirect impacts could in fact be larger. Such uncertainties about the causality could be reduced by using a transport model instead of a survey to estimate the impacts, since for a survey exogenous effects are impossible to control. Nonetheless, indirect impacts are extremely important in the evaluation of transport projects, especially because frequently congestion reduction is one of the objectives of the implementation of mass transit. This objective can only be evaluated by including the indirect impacts. Therefore, it is recommended to include indirect effects in future studies.

Although the comparison between the models is solid, there is an exception to this, because some indicators are attributed the maximum or minimum standardized value. As a result, the difference is not accurately represented for that indicator, but also the aggregated indicators are affected by this. For example, for equity both lines score the maximum standardized value, even though the Metro performs better. As a result, this difference in performance is not expressed in the aggregated values. Alternatively, excluding a maximum and minimum value results in some very high or low standardized values. For example, in that case the standardized value for operating and maintenance costs for the Metrobús would be more than five. This would increase the economic score by 0.75 and the overall score by 0.25. Hence, one indicator would have very large impacts on the outcomes, which is undesirable. Hence, despite the disadvantages of minimum and maximum values, their use is still recommended.

The literature review mentioned that the Metrobús line is not a full BRT line, for example because of the on-board fare collection and low-capacity buses. An application of the BRT standard scoring methodology developed by ITDP (2013) shows that the line does not score high enough to be awarded the bronze standard and does not comply to BRT standard's minimum conditions. However, this scoring is based on personal observations and has not been conducted elaborately, so results are not accurate. Nevertheless, it is clear that the Metrobús line is not a full BRT line. Therefore, an analysis has been made to estimate the Metrobús line's impacts if it were implemented as a full BRT, such as the first Metrobús line on Insurgentes Avenue. To do so, the number of passengers per kilometer of infrastructure was expanded according to passenger numbers for Metrobús line one. This is an extremely hypothetical situation, because the road network does not allow for such a system, and the potential demand is much lower for the fourth line than the first line. Furthermore, construction costs and operating and maintenance costs have not been adjusted, while especially the former would have been significantly higher. However, it serves the purpose of giving an indication of the difference in impacts if a full BRT line was implemented, as well as an indication of the sensitivity to the number of passengers.

The results show that in this situation the performance of the Metrobús increases considerably. In fact, the Metrobús performs better than Metro on all indicators, except equity, travel time savings and revenues. For most other indicators, the Metrobús performs much better. Performance especially improves for travel time savings, air pollution, revenues and safety. As was already explained in section 7.1, these indicators largely depend on the fraction of users of the entire population. This fraction increases significantly in this hypothetical situation, which explains the performance improvement for the indicators. This once again confirms the sensitivity of the analysis to the number of users. However, more importantly, it highlights that a high-capacity transit line provides significantly higher impacts than a low-capacity line, especially if effects on the whole transport system within the zone of influence are taken into account.

The attributed flags and standardized values indicate that in this hypothetical situation the Metrobús performs much better than the Metro; overall standardized values differ by more than one point. Although these impacts are exaggerated because these effects could never have been accomplished for these costs and the demand is too high for the service area, this does show that BRT performance can be very high. Additionally, it shows that a BRT system can in fact rival an MRT system in terms of impacts. Furthermore, these benefits can be provided at a fraction of the cost, as the literature on construction costs indicates.

7.4 POLITICAL CONTEXT

This section discusses the results in relation to the political context in Mexico City. First of all, the results are compared to the implementation objectives outlined in chapter four. Secondly, this section compares the results with existing policies in Mexico City. This mainly concerns how the implementation of the lines contributes to policies for Mexico City.

7.4.1 POLICY OBJECTIVES

The main objectives of the construction of the fourth Metrobús line were to reduce travel times by at least 40%, attain a modal shift from private vehicles, improve integration with other transport modes and to offer supply for trips destined for and originating from the bus terminal, suburban train, airport and historic center. First of all, the travel time reduction of 40% is not attained, since travel time savings are only 11.5%. However, direct travel time savings are 39.2%. Probably, the 40% reduction that is aimed for, concerns only the direct travel time savings. Hence, this objective is not achieved, but is very close. Furthermore, the travel time savings of 50% presented at the Metrobús visit are higher than the savings found in this study. Secondly, the modal shift from private vehicles is 14.3%. Although the objective was not quantified, it is likely that this objective is achieved, given values found in literature and for the Metro line. Metrobús claims a modal shift from cars of 17% equaling 12,000 daily trips. However, the modal shift from car is only 6.2%, or 4,088 daily trips. Hence, their results are exaggerated, since even if taxis are included the modal shift is lower at 14.3%, or 9,386 daily trips. Thirdly, the transport mode integration was not evaluated in this framework. Nonetheless, the interviews with Onésimo Flores and Emelina Nava provided insights in the general integration of transport modes, which is not very positive. Furthermore, the visit to the Metrobús line showed that integration with other modes is not good, since no physical integration exists and transfer times are relatively high. Fourthly, a traffic supply is offered to the bus terminal, historic center, airport and commuter train. However, this is most significant to the airport, because the number of transport options was limited. On the other hand, the higher fare significantly reduces the use of this line. For the other destinations, connections with the Metro already existed, so the improvement is only marginal, especially considering the low demand for the line. Overall, most objectives are difficult to evaluate because most are not quantified. Nonetheless, it can be stated that not all policy objectives are attained, which is mainly the result of the low demand of the line.

Chapter four showed that the main objectives of the Metro line implementation were to reduce daily travel times, increase equity, reduce emissions and improve network connectivity. First of all, the travel time reduction objective was not quantified, which makes it difficult to conclude if it was achieved. There are travel time reductions, but if this reduction is sufficient cannot be decided on available information. Nonetheless, travel time reductions are significant at 22.7%, which makes it likely that the objective is attained. Secondly, the equity increment of 39.8% is very high. Although no quantitative objective was set for this, it is assumed that this objective is met given the high improvement and the equality of travel times according to income in general. Thirdly, the emission reduction objective was not specified further. However, both pollutant emissions and CO_2 emissions have reduced significantly. Hence, the emission reduction objective has been achieved. Finally, the network connectivity objective is more difficult to evaluate, because this was not an indicator of the analysis. Nevertheless, the line connects with four other Metro lines and offers access to the Metro network to an area previously not serviced. Thus, this objective is likely to have been attained. Overall, this means that all policy objectives of the construction of the Metro have been accomplished. However, it is important to note that these objectives were not quantified, which makes it difficult to judge if objectives have been fully realized.

The overall results show that the two transit lines perform very similarly. However, the most appropriate system depends largely on the policy objectives of the construction. For example, if the objectives are economic or environmental benefits, then the Metrobús performs better, while for social objectives the Metro is preferable. The results show that to achieve high travel time savings, equity improvement, safety enhancement, air pollution reduction and climate change mitigation, the Metro is preferable over the Metrobús. On the other hand, if a low-cost transit line or modal shift is desired, the Metrobús is superior. Meanwhile, if absolute changes are regarded, the Metro is also preferable for modal shift. However, it is important to note that the difference in passenger demand results in low overall effects for the Metrobús. For example, if passenger travel time savings are the main objective, then the Metrobús and Metro perform similarly. The same holds for the safety perception improvement.

Hence, politicians should select the most appropriate transit system based on their policy objectives. The goals they want to achieve should be the most important aspect in the decision making process. If goals are attained largely depends on the number of passengers. Thus, much of the system selection depends on the expected demand. The first Metrobús line has shown that BRT capacity can rival MRT capacity, if implemented correctly. Similar results were found for Bogotá's TransMilenio (Wright and Hook, 2007). Hence, if a supply and demand study is conducted for a corridor, it is recommended to execute it for both a BRT and MRT system. Based on these outcomes, the difference in the magnitude of impacts can be estimated. Especially considering the limited budgets for transport projects, this is important because based on this the efficiency of the investment can be approximated. This research shows that the Metrobús is economically more efficient. Nonetheless, for less tangible goals such as livability or excluded indicators such as land value or land use impacts, this may not be the case. Furthermore, a minimum size of impacts may be required, regardless of economic efficiency. For example if a congestion reduction is required, a Metro may economically be less efficient, but still preferable because only this system can result in the essential road vehicle reduction, particularly if a Metrobús line will remove two lanes from other road transport modes.

On the other hand, the transport specialist interviews showed that political aspects are considered the most important in the decision making process. Hence, it is also important to consider which of the systems is politically more feasible, because without political support implementation is impossible. A major consideration for this is the number of existing operators on the corridor. Although Metrobús implementation has become easier over the years, operators that are left out of the negotiation process fear to lose business. Hence, if there is a large number of existing operators, a Metro line is preferable, while a small number of operators means Metrobús implementation is easier. Another important aspect is the cost of the construction, which is favorable for Metrobús. Furthermore, this ex-post evaluation shows that for Metrobús a larger part of the construction costs is paid for by the users through ticket fares. This means that tax payers do not finance a large amount of the construction. Additionally, the fast implementation of Metrobús favors political feasibility, because the planning and implementation can be completed within the six-year term of the mayor. Nonetheless, ultimately the choice between Metro and Metrobús for a large part also depends on the subjective preferences of the mayor.

7.4.2 EXISTING POLICIES IN MEXICO CITY

This section discusses how the impacts of the two transit lines contribute to the policy plans for Mexico City, which were elaborated on in section 4.2.2. Some of these policy objectives are closely related to the indicators in this framework, while others are more intangible goals. Both Ciudad de México (2013b) and SEDEMA (2007) have set objectives to reduce pollutant emissions and the impact on climate change. Both of these were incorporated as indicators in this ex-post evaluation. The discussion on these indicators shows that the relative emission reductions are significant, especially for the Metro. However, in terms of absolute emission reductions, the reduction for all transport emissions in the entire MCMA are low, ranging from 0.01% to 0.05% for Metrobús and 0.3% to 0.5% for Metro. Although no quantitative emission reduction goals have been set, the magnitude of these reductions is too small to achieve the objectives. However, especially the Metro line does provide a significant emission reduction and aids in the accomplishment of the goals. Nonetheless, other mitigation policies, such as increased fuel efficiency, are required.

The SEDEMA (2007) also set the reduction of the number of vehicles on the road as a goal. Both transit lines contribute to the attainment of this goal, given the modal shift they impose. The Metro reduces the number of working day road transport trips by 428,525, of which 47,892 are by private mode. The Metrobús line reduces working day road transport trips by 36,741, of which 9,386 are by private mode. Although the number of trips does not represent the number of reduced vehicles on the road, the number of vehicles on the road is related to this, because if there is less demand, less public transport vehicles will offer services. Additionally, the reduction of private vehicles relates more directly to the number of vehicles on the road, except for taxis. Hence, especially the Metro project helps in achieving the goal of reducing the number of vehicles on the road. Furthermore, Ciudad de México (2013b) and Comisión Ambiental Metropolitana (2011) have set the objective to replace microbuses by medium- and large-capacity vehicles. Given the significant modal shift from microbus, combi and autobus, many trips have been replaced by large-capacity vehicles (buses and Metro wagons). For the Metrobús, these have been directly replaced by the scrapping of the previous vehicles of the operators. For the Metro, reduced demand will have resulted in a lower number of low-capacity vehicles. Given the difference in absolute modal shift, especially the Metro contributes significantly to the replacement of low-capacity vehicles for high-capacity vehicles.

Ciudad de México (2013b) set as an objective to improve the equality between social groups. The equity indicator shows that this objective has been achieved, given the equity improvement for both transit lines. Furthermore, especially the Metro line improves equality between social groups, since the line connects one of the richest boroughs with two of the poorest. This means that more equality is created, and that social inclusion is improved as well. Also, the modal shift from private vehicles to public transport, particularly by richer groups, means that people from various income groups share the same transport modes, improving equality. Especially for the Metrobús the variation in incomes is high, indicating more equality between social groups.

Furthermore, Ciudad de México (2013b) set the objective to develop infrastructure in the eastern parts of the city. As mentioned before, the Metro connects the southern central part of the city with the southeast, which means that infrastructure is provided to the eastern parts of the city. The Metrobús line also developed infrastructure in the east, especially in the part between the airport and San Lázaro. However, this section is used minimally, indicating that the infrastructure development is not as significant as the development for the Metro. This also relates to the objective to improve the public transport service (SEDEMA, 2007). Especially the Metro line offers a significant improvement, as it offers a mass transit system to an area previously only served by low-capacity public transport. Moreover, it provides an essential east-west connection between four lines running from north to south. This means that transfers between those lines has become significantly more efficient. The lower demand for the Metrobús indicates that the service improvement is not as significant. However, it does significantly improve the public transport service in the city center and provides an essential connection the international airport. The connection with other Metrobús lines also improves the connectivity within the network. Hence, both systems contribute to improving the public transport service in Mexico City, although the Metro makes a more significant contribution.

Ciudad de México (2013b) has the goal to promote non-motorized transport, for example by providing bicycle parking at public transport stations. This is not evaluated in this framework. However, the interviews provided some insights in the integration of transport modes. This integration is insufficient and neither the Metro line nor the Metrobús line made changes to this.

Furthermore, the latest Metrobús line (five) does include cycle paths, but these are not perpendicular to the corridor, meaning that bicycling as access mode is not promoted. On the other hand, the use of public transport does promote walking, because this is the most common access and egress mode. Therefore, both lines do contribute to the promotion of walking as NMT mode, but bicycling is not promoted. Additionally, Comisión Ambiental Metropolitana (2011) also set the objective to promote bicycle use, but also to improve intermodal transport and transfers and connections. Both transit lines provide additional transfers between lines of the systems, improving the connections within the network. However, for the Metrobús these transfers are not within the same station, so integration can still be improved. Furthermore, intermodal transport is promoted through transfer possibilities between modes, but the integration between the stations is still lacking, especially for Metrobús. For the Metro, two CETRAMs have been implemented (at Tláhuac and Periférico Oriente), improving intermodal transfers and promoting multimodal transportation. Hence, the Metro line contributes more to the attainment of this objective than the Metrobús.

7.5 RESEARCH LIMITATIONS

In the previous sections several limitations of the research were already discussed. This section discusses some additional research limitations that were not already addressed in the previous sections. These limitations concern methodological limitations of the evaluation framework and some limitations inherent to the context of the two transit lines.

7.5.1 METHODOLOGICAL LIMITATIONS

One of the limitations of the evaluation framework is that it does not incorporate a counterfactual situation. The impacts are based on a comparison of the current situation with the previous situation. However, if the transit line would not have been implemented, the situation would have been different than it was previously, for example due to an increase in traffic volumes. Therefore, a comparison with this counterfactual situation would have been more appropriate, because this better portrays the improvement due to project implementation. Since it is likely that in the counterfactual situation traffic volumes increase, the impacts calculated in this evaluation would have been larger. Hence, this ex-post evaluation underestimates the impacts through excluding a counterfactual situation. Nevertheless, the framework does remain useful to compare the two transit lines. The main reason that the incorporation of a counterfactual situation is difficult is because a survey is used as the main data collection method, since this does not provide any information on an alternative, fictional situation. Hence, it would be interesting to conduct a similar evaluation using transport models, in which a model establishes current travel patterns (input) and compares this with a situation in which the new transit line is removed from the model and travel patterns are distributed differently throughout the city (output). This poses several advantages. First of all, a counterfactual situation can be used to compare the results to. This way, it is ascertained that impacts are endogenous and not resulting from other changes. Secondly, in such models second order effects are included. For example, latent demand resulting from congestion reduction is part of such analyses. This means that the estimation of impacts is more accurate. Unfortunately, such transport models are currently unavailable in Mexico, but could provide useful insights for future research.

The time after which the ex-post evaluation was conducted is also a limitation of this research. The surveys were conducted approximately one year after implementation. However, the literature review showed that in other studies this ranges from one to five years. The timing of the evaluation depends on the causality of the observed effects, which is clearer if the evaluation is executed shortly after implementation, and on the observability of impacts, which is clearer after a longer time. For this evaluation a relatively early evaluation is conducted, which means that the causality issue can be disregarded, but that perhaps not all impacts are observable yet.

Thus, the impacts are possibly somewhat underestimated. Nonetheless, it is recommended to conduct the evaluation within a one to two year period after implementation, because while conducting the surveys it was experienced that for some respondents it was difficult to relate to the previous situation. Furthermore, some respondents did not make the trip previously, for example because of a new residential location or new job, and therefore had to be excluded from the survey. These issues will be even larger if the evaluation is conducted three to five years after implementation.

Another methodological limitation of this evaluation framework is that a limited number of indicators is used. The theoretical framework showed that there is no consensus in literature on which indicators should be used in transport project evaluation. A long list of twenty-six indicators was derived from many references and only nine were selected as part of this evaluation framework. Therefore, the evaluation could have been much more comprehensive if more time would have been available. This would have significantly improved the quality of the evaluation. Personal experience also showed that the indicators that are included in the framework are always a point of discussion. Some interesting indicators such as land value and livability impacts were excluded because of the complexity of such indicators. Furthermore, travel time reliability is a more relevant indicator than initially anticipated. Experience showed that delays are common for some Metro lines. Furthermore, reliability is much lower for minivans and regular buses. Hence, significant travel time reliability improvements are likely to result from the implementation of both lines. Therefore, it is recommended to conduct research on these, and other, indicators in further research. Nonetheless, this evaluation framework includes some of the most frequently used indicators (e.g. travel time savings and climate change effects), while also some more innovative indicators are included (e.g. equity). Hence, the research results are relevant and also add knowledge to transport project evaluation methodology.

Somewhat related to this indicator limitations, is that the quality of the service is not evaluated. This concerns aspects such as floor-level boarding, off-board payment, crowding, in-vehicle temperature and accessibility for handicapped. Such qualifications of the level of service are important attributes that influence the modal shift, for example. Furthermore, the quality of service is important for the income groups that shift to the new transport line. If the quality rivals that of private vehicles, higher income groups are more likely to shift towards a mass transit mode. It is therefore likely that the impacts in this evaluation are related to the quality of service. A higher quality of service means a higher modal shift from higher incomes and thus private vehicles. This means that impacts on congestion and emissions are much larger. For this research, the average income of Metrobús passengers is almost double the income of Metro passengers. This means that the quality of service is probably higher for the Metrobús, since more high-income people are willing to shift to Metrobús. This is in line with expectations, because the Metrobús puts a more distinct focus on quality of service and branding, while the Metro system focuses more on moving many people quickly. Thus, for future research it is recommended to conduct a comparative study on the service quality of the Metrobús and Metro systems.

Another limitation of this research is that network effects are excluded. The Metro line connects to a much larger and better integrated network than the Metrobús. This means that larger benefits are acquired if travelers shift to Metro than to Metrobús. For passengers, such benefits include a larger network which means more destinations can be accessed for the same ticket price and travel time savings are higher because of a denser network. Additionally, the better integration of Metro stations results in significantly more advantages if the Metro network is accessed than if the Metrobús network is accessed. Hence, network effects have a large influence on the modal shift. Furthermore, the denser network means that higher travel time savings are acquired for those passengers that enter the Metro system at line twelve, because they have more options to reach their destination. This means that the Metro line is profiting more significantly from the network effects than the Metrobús line. Hence, some of the higher indicator values for the Metro are due to these network effects. Thus, for future research it is recommended to compare a BRT line with a MRT line in a situation in which the networks are of similar length and quality. Another interesting study would be to investigate the size of these network effects and how this influences the indicators used in this evaluation framework.

The most important question to be answered is if the methodology developed in this research is applicable to other contexts. First of all, it is important to consider if the context is similar, because the indicators that are incorporated in this framework are not applicable for every context. Based on the context, some indicators can be removed or added. However, for similar research within Mexico, this framework does not require changes. Furthermore, the calculation techniques are useful for other contexts. Secondly, the input data for the framework are relatively straightforward. The surveys developed can be used as standard format for other studies, although some questions have to be adapted slightly, such as the income groups. Additionally, the emission factors are case-dependent and need updating for different contexts. The same holds for the previous modal split within the zone of influence. On the other hand, VOTs are easily based on income levels and the CTVs used in this study can form the basis for the flag model. Furthermore, applying the ex-post evaluation for new Metrobús lines is more straightforward, as this only requires conducting new surveys. Third of all, the flag model as aggregation method proved useful for comparative purposes, although for evaluative goals the model is less useful. However, this is mainly because of the different methodologies applied in the studies on which the CTVs are based. Therefore, conducting a series of ex-post evaluations using this framework will provide extremely valuable data to improve the CTVs. For example, if ex-post evaluations are conducted for many of the recently implemented BRT systems in Mexico, these outcomes can be used to compare the projects using the flag model. This also improves the evaluative properties of the flag model, because CTVs are based on research using the same methodology. Fourthly, it is important to take into account that the framework only evaluates a transit line and does not take into account the political context. Political decisions are not based on merely rational arguments, but also sentiments, personal preference and ease of implementation play an important role. Hence, the evaluation results can be used to convince policy makers and others of the positive impacts of transit lines, but ultimately the decision is also made based on other arguments. Concluding, the evaluation framework is definitely applicable to other projects, particularly in Mexico, but also to a different Latin American context. Hence, it is recommended to conduct ex-post evaluations using this methodology for more recently implemented transit lines in Mexico. This improves the utility of the flag model and thereby the comparability and evaluation of line performance. This can give a complete view of the successfulness of BRT and MRT project throughout Mexico.

7.5.2 CONTEXTUAL LIMITATIONS

The major contextual limitation is that the fourth Metrobús line is not a full BRT line. This results in a lower number of passengers due to a lower service level. The effects of this lower passenger number were already discussed comprehensively in the previous sections. This is the major limitation of this research since it influences almost all the indicators. However, causality issues made it difficult to evaluate another Metrobús line, so no other option was available. Nonetheless, it is strongly recommended to conduct an ex-post evaluation for Metrobús line five, since this line is a full BRT line and can provide a better comparison with the Metro line.

Another contextual limitation is that the two lines are in different locations. Hence, even if both lines were exactly equal, the different location could still result in unequal impacts. For example, the Metro line serves poorer boroughs than the Metrobús line. As a result, the likelihood of a modal shift from private vehicles is lower for the Metro, since the theoretical framework showed that car ownership increases along income. Thus, even if the Metro would attract a higher proportion of car users within the zone of influence, this does not necessarily mean that it performs better on the modal shift indicator. Furthermore, the exogenous effects are different for the two locations. Hence, if more other developments took place simultaneously for one transit line, less of the impacts are attributable to the transit line. This mainly influences the indirect impacts. Unfortunately, this limitation is inherent to the comparison of several transit lines, because due to competition two transit lines are never constructed in the same location. Nonetheless, impacts can be corrected for differences in socio-economic characteristics, such as average income and car ownership. However, data limitations often make this difficult and such corrections would most likely be a thesis on its own.

The zone of influence is another limitation of this study. The main issue is that for the Metro the number of trips within the zone of influence is based on the ex-ante appraisal by Spectron Desarrollo (2009) and for the Metrobús on the supply and demand study by CETRAN (2009). Since these are different consultancies, a different methodology was used for the Metrobús and Metro. This means that the size of the zone of influence is not determined in exactly the same way. Hence, possibly the zone of influence of one of them is larger. As a result, the total number of previous trips would have been different if another methodology was applied. This means that effects, particularly relative changes, would be different if a smaller number of previous trips was used. For example, the absolute emission reduction is still correct, but the total previous and current emissions would be lower, resulting in a larger relative emission reduction. Hence, for future studies it is recommended to develop a methodology for the estimation of supply and demand and apply this methodology to all transport projects.

A final limitation of this study is the confidence level of the surveys. The large expansion factors indicate that for some boarding stations or transport modes, the expansion factor is very large. Furthermore, for the Metro some stations were merged for the analysis, because otherwise the number of respondents was too low. Hence, for future research, it is recommended to increase the sample size to gather more accurate results. However, temporal and financial constraints will often limit the sample size, as was the case for this study. Furthermore, the literature review showed that beyond a certain population size, the required sample size does not increase along with the population. Hence, expansion factors can be large and still provide accurate results. Nonetheless, for this study a larger sample size, especially for the non-users, would have produced more accurate results.

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS

This chapter discusses the conclusions and recommendations of this research. First of all, the conclusions are presented, which address the research questions that were formulated in chapter two. Secondly, the research limitations are discussed briefly. Finally, several recommendations are made, concerning improvements of the evaluation framework, as well as recommendations for future research.

8.1 CONCLUSIONS

Although ex-ante appraisal is frequently conducted for transport projects, ex-post evaluations are only carried out occasionally. However, ex-post evaluations can provide important insights in actual, and not estimated, project performance. These insights are useful to improve transport planning and transport system design. Current transport evaluation practice puts a distinct focus on economic appraisal, but often underrepresents or completely excludes social and environmental impacts. Furthermore, BRT systems' popularity and implementation has increased, especially in Latin American countries, although many still regard MRT a superior alternative. However, arguments are often based on sentiments and personal preference and not on rational arguments. One of the reasons for this is that no studies exist that evaluate and compare the impacts of both systems. Therefore, impact comparison is only possible using various studies that apply different methodologies. In order to bridge this knowledge gap, the objective of this research was to develop and apply an ex-post evaluation framework to assess and compare the impacts of BRT and MRT systems in Mexico. The framework was tested in Mexico City, one of the few cities in which both a BRT and MRT system exists. The ex-post evaluation was conducted for the fourth Metrobús line and the twelfth Metro line, both of which started operation in 2012.

In order to develop an ex-post evaluation framework, a literature review on transport evaluation theories was conducted. Based on this literature review several choices for the evaluation framework were made. First of all, indicators were grouped according to the social, environmental and economic concepts of sustainable development. Secondly, only economic indicators were monetized, because otherwise social and environmental indicators are represented insufficiently in the outcomes. Third of all, if applicable, impacts were expressed in relative change to allow for comparison between the two transit lines. Fourthly, an egalitarian approach of indicator calculation was preferred to account for the large (income) inequalities in Mexico City. Finally, indicators were aggregated and evaluated using the flag model. This model uses impacts found in literature to evaluate the performance of the indicator. The outcomes of the evaluation are shown in Table 8-1.

The social indicators included in the framework are equity and safety. The results show that both transit lines effectuated a significant equity improvement, although the Metro line performs slightly better. Compared to other studies, this performance is good. Furthermore, the Gini-indices indicate that the travel time savings are distributed very equally over income groups. In terms of safety both lines show improvement and especially the Metro line. However, compared to other studies these safety improvements are low to medium. The safety improvements are mainly enjoyed by passengers, while indirect safety impacts are minimal.

The framework consists of three environmental indicators: air pollution, climate change and modal shift. Both air pollution and climate change emission reductions are observed for both lines, but these are higher for the Metro. However, these are lower than the emission reductions found in other studies. The emission reductions resulting from the Metro line have some impacts on total emissions in the MCMA, but for Metrobús these reductions are negligible on a city scale. The modal shift from private vehicles is highest for Metrobús. Compared to other studies, the modal shift is high for Metrobús and low for Metro. Conversely, the Metro implementation results in a larger absolute modal shift, especially from low-capacity public transport.

Four economic indicators are part of the evaluation framework. Firstly, the Metro performs better in terms of travel time savings. Compared with values in other studies, both transit lines perform below the average. However, direct travel time savings are much higher and above the average. Secondly, construction costs are much lower for Metrobús. The construction costs of the Metrobús line are below the average construction costs of other mass transit systems, while the Metro construction costs are above the average. However, in comparison with other MRT systems the construction costs are lower than average. Thirdly, a similar trend is observed for the operating and maintenance costs, which are higher for the Metro and above the average of other studies. Meanwhile, Metrobús operating and maintenance costs are well below average. Finally, these operating and maintenance costs are more than compensated for by the revenues. For both transit lines, the revenues exceed the operating and maintenance costs, indicating operating profits. However, Metro revenues are much higher, also in comparison with other systems, while Metrobús revenues are low.

Aggregation of these indicators using the flag model shows that the Metrobús performs better for economic and environmental indicators, while the Metro has a higher social performance. Overall, the two transit lines are almost equal, although the Metrobús performs slightly better. Furthermore, standardized values indicate that both lines perform just under average compared to other studies. However, it is important to note that the framework more elaborately evaluates economic and environmental impacts than social impacts. In terms of economic profitability, the outcomes of the Metro strongly depend on the value of time. Meanwhile, the Metrobús is profitable in every VOT scenario. Additionally, the B/C ratio indicates that economically the Metrobús is more efficient. This is also confirmed by the economic efficiency of individual indicators. However, the efficiency per user trip, representing the impact of each passenger trip, is higher for Metro for environmental indicators. This shows that in order to reduce air pollution and climate change, the Metro system is more effective.

	Indicator	Abbr.	Metrobús Indicator value	Metrobús Standardized value	Metro Indicator value	Metro Standardized value
Economic	Travel time savings	TTS	11.1%	-2.00	21.7%	-0.64
	Construction costs	CON	$1,468,890	1.12	$65,853,454	-0.49
	Operating & maintenance costs	OM	$178,380	2.00	$1,733,957	-2.00
	Revenues	RE	$267,992	-1.34	$2,024,209	1.49
	Economic	**EC**	-	**-0.05**	-	**-0.41**
Social	Equity	EQ	31.3%	2.00	39.8%	2.00
	Safety	SA	23.4%	-0.86	29.6%	-0.40
	Social	**SO**	-	**0.57**	-	**0.80**
Environmental	Air pollution	POL	-12.3%	-1.47	-29.6%	-0.53
	Climate change	CC	-4.9%	-2.00	-22.8%	-1.17
	Modal shift	MS	14.3%	1.10	7.5%	-1.09
	Environmental	**EN**	-	**-0.79**	-	**-0.93**
	Overall	**OV**	-	**-0.09**	-	**-0.18**

Table 8-1: Overview of flag model and corresponding flags for all indicators for Metrobús and Metro.

8.2 LIMITATIONS

One of the main limitations of this study is the use of the flag model. Since the standardized values are based on a comparison with literature values, and these often only include direct effects, the performance of both lines appears low. However, if only direct effects are considered, the lines perform above the averages in literature. On the other hand, including indirect effects means that the framework indirectly incorporates the size of impacts. This is preferable since this means impacts on the transport system and not just impacts for passengers are considered. Additionally, mass transit projects often aim to reduce congestion, which can only be evaluated with indirect impacts. Furthermore, the ranges in CTVs differ significantly per indicator. As a result, a small difference between the lines for one indicator results in a higher difference in standardized values than for another indicator. Finally, a minimum and maximum standardized value is set for this analysis. This means that even though a line performs better, this may not be expressed in the standardized values if both have the maximum or minimum value.

Unfortunately, time limitations restricted the data collection for this research. As a result, some indicators were estimated using techniques that are suboptimal. First of all, the safety indicator is based on the change in safety perception. However, it is uncertain if this perception is directly proportional and if the relative change in safety perception accurately represents the change in safety. Secondly, the impacts on emissions are estimated using average emission reductions per trip. However, trip length is disregarded, as well as the actual change in the number of (public transport) vehicles on the road. Hence, it is possible that public transport vehicles continue operating with fewer passengers. As a result, the emission reduction impacts would be much smaller. Nonetheless, the sensitivity analysis showed that this significantly impacts absolute emission reductions, but that relative emission reductions are hardly affected. This means that the framework results are influenced minimally. Thirdly, the number of indicators in the framework is also limited due to time availability. For example, travel time reliability would be an interesting additional indicator to evaluate.

Some contextual limitations of the case study exist. The major limitation is that the Metrobús line evaluated in the case study is not a full BRT line. Thus, capacity and demand are lower and consequently impacts are smaller than they would have been for a full BRT line. This means that the comparison between BRT and MRT disadvantages the former. Nonetheless, the evaluation of the individual transit lines is valid. Secondly, network effects are excluded. These are expected to be larger for the Metro, because its network is significantly larger. Thus, Metro impacts are probably larger because of the larger benefits enjoyed due to its network. Thirdly, the zones of influence are based on ex-ante appraisals which do not apply the same methodology. Hence, the zones of influence are not perfectly comparable. Fourth of all, exogenous effects may affect the estimated impacts as well, particularly for the indirect impacts. This reduces the accuracy of the results found in this evaluation. Finally, the number of surveys is limited, which means the expansion factors are large, especially for the non-user sample.

BRT and MRT systems are inherently very different, which makes it difficult to accurately compare them in an evaluation framework. Especially the standardization of values is difficult because some indicators, especially the financial costs and revenues, differ significantly in magnitude. Additionally, the inherent differences make it difficult to apply a single framework. For example, the lifespan of an MRT line is much longer than the lifespan of a BRT line. This means that the project horizon applied in this framework is too long for the Metrobús, or too short for the Metro. Furthermore, the framework is more useful to compare several BRT or MRT lines, than to compare between the two. However, this limitation is inherent to any evaluation that attempts to compare two transport systems.

8.3 RECOMMENDATIONS

The results of this study have several political implications. First of all, the results are useful to communicate the impacts of the lines to the public and bus operators, since this can help convince them of the positive impacts and usefulness of implementing additional corridors. Secondly, the Metrobús is a more efficient system, while the Metro is more effective, since absolute impacts are considerably larger. Third of all, politically the Metrobús is more feasible, particularly because of the lower construction costs. The selection of which system should be implemented in which location largely depends on the political objectives. In terms of large environmental impacts the Metro is preferable, as well as for safety, equity and travel time impacts. On the other hand, the Metrobús is preferable to implement a low-cost mass transit system that results in a significant modal shift from private modes. Furthermore, if a demand study is conducted, it is important to include both Metro and Metrobús in this study, because the size of the impacts largely depends on the demand. Hence, politicians should choose a Metro or Metrobús system based on their objectives and the expected demand for each line and not decide which system they prefer before such studies.

Improvements in the evaluation framework can be made in several ways. First of all, if data is available, the safety indicator should be optimized using the change in the actual number of accidents instead of safety perception. Secondly, air pollution and climate change impacts are more accurately measured using the change in vehicle kilometers resulting from the modal shift. However, this requires extending the data collection. Thirdly, it is recommended to apply a longer project horizon for the evaluation of a MRT line than a BRT line. Alternatively, the residual value of the infrastructure, stations and vehicles can be used to compensate for the difference in lifespan. Fourth of all, if time allows, the incorporation of a counterfactual situation is suggested. Finally, in order to prevent causality issues, it is recommended to conduct the evaluation within one to two years after operation begins.

For future research it is recommended to expand the evaluation framework. The framework will give more useful results if more indicators are included, which allows for a more complete comparison between BRT and MRT. Such additional indicators can be travel time reliability, livability and land use impacts. Furthermore, an evaluation of the service quality of both MRT and BRT systems is suggested, because this is an important determinant of the modal shift from private vehicles. However, this evaluation is best conducted separately from an impact evaluation such as this one. Additionally, it is recommended to conduct a similar evaluation using transport models instead of surveys. This way, second order effects are included and exogenous impacts are reduced. However, this is very dependent on the availability of a transport model.

The evaluation of two transit lines is not sufficient to settle the debate on BRT or MRT. However, it does provide a first step towards additional evaluations of BRT and MRT systems. In order to improve the comparability of the results it is recommended to conduct an ex-post evaluation of the fifth Metrobús line, which was implemented last year. This is a full BRT line and will improve the comparability with the Metro line. Furthermore, if time and financial means permit, it is recommended to increase the sample sizes, especially for non-users, in future studies. It is recommended to conduct these future studies for recently implemented transit lines in Mexico, as this ex-post evaluation framework was developed specifically for this context. Since many Mexican cities are currently implementing or have recently implemented BRT systems, there is a large number of BRT lines that can be evaluated. The outcomes of these studies are useful to improve the CTVs of the flag model. Additionally, this provides insights in the performance of BRT and MRT projects throughout Mexico. Although this framework is most applicable for the Mexican context, some adjustments allow for application in other contexts as well, particularly in Latin America. If such future research aim at comparing BRT and MRT it is recommended that both systems have a similar length and service quality so network effects are equal.

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AN EX-POST EVALUATION FRAMEWORK FOR BRT AND MRT IN MEXICO

A study on the impacts of Bus Rapid Transit and Mass Rapid Transit in Mexico City

APPENDIX

MASTER THESIS
THIJS TEUNISSEN
31 MARCH 2014

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EFL STICHTING

APPENDIX A LOCATION OF POOREST AND LEAST POOR BOROUGHS

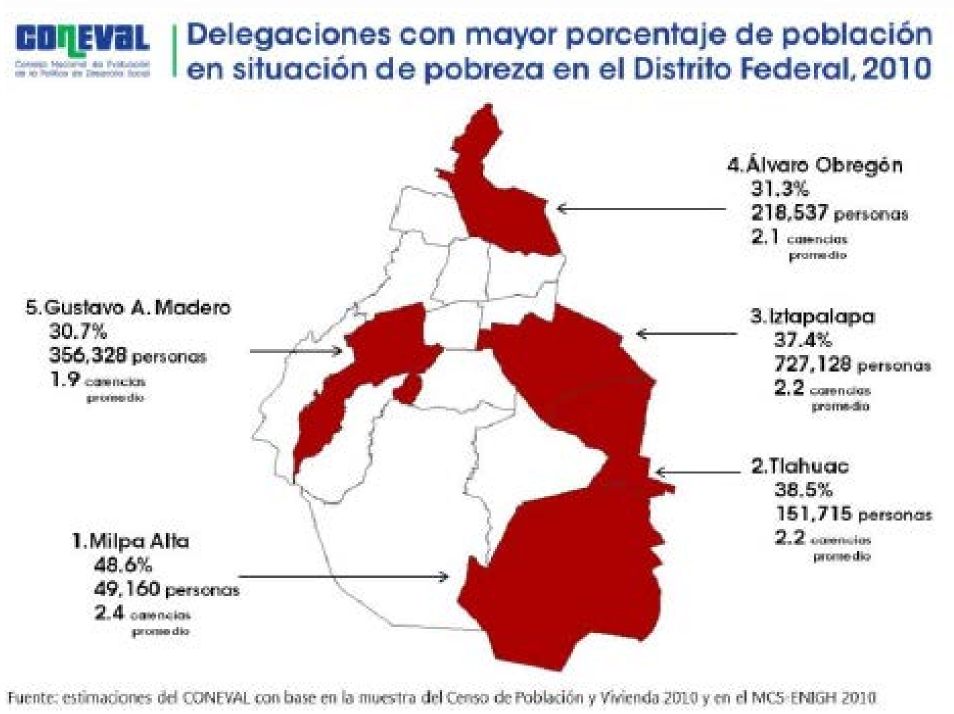

Figure A-1: Location of Federal District's boroughs with highest poverty (CONEVAL, 2012a).

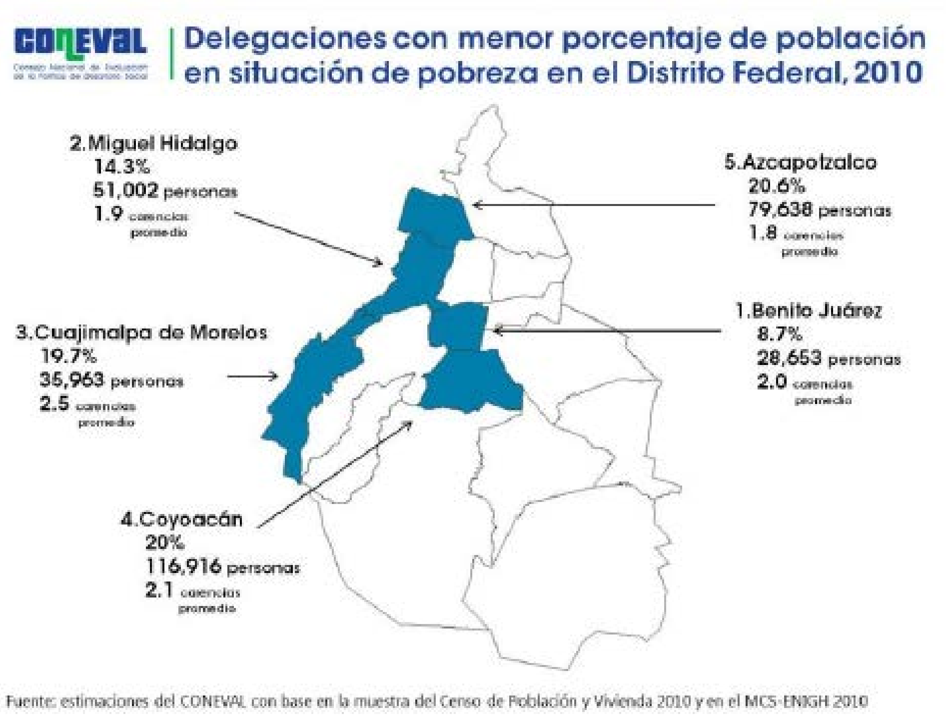

Figure A-2: Location of Federal District's boroughs with least poverty (CONEVAL, 2012a).

APPENDIX B GINI-INDEX PER BOROUGH

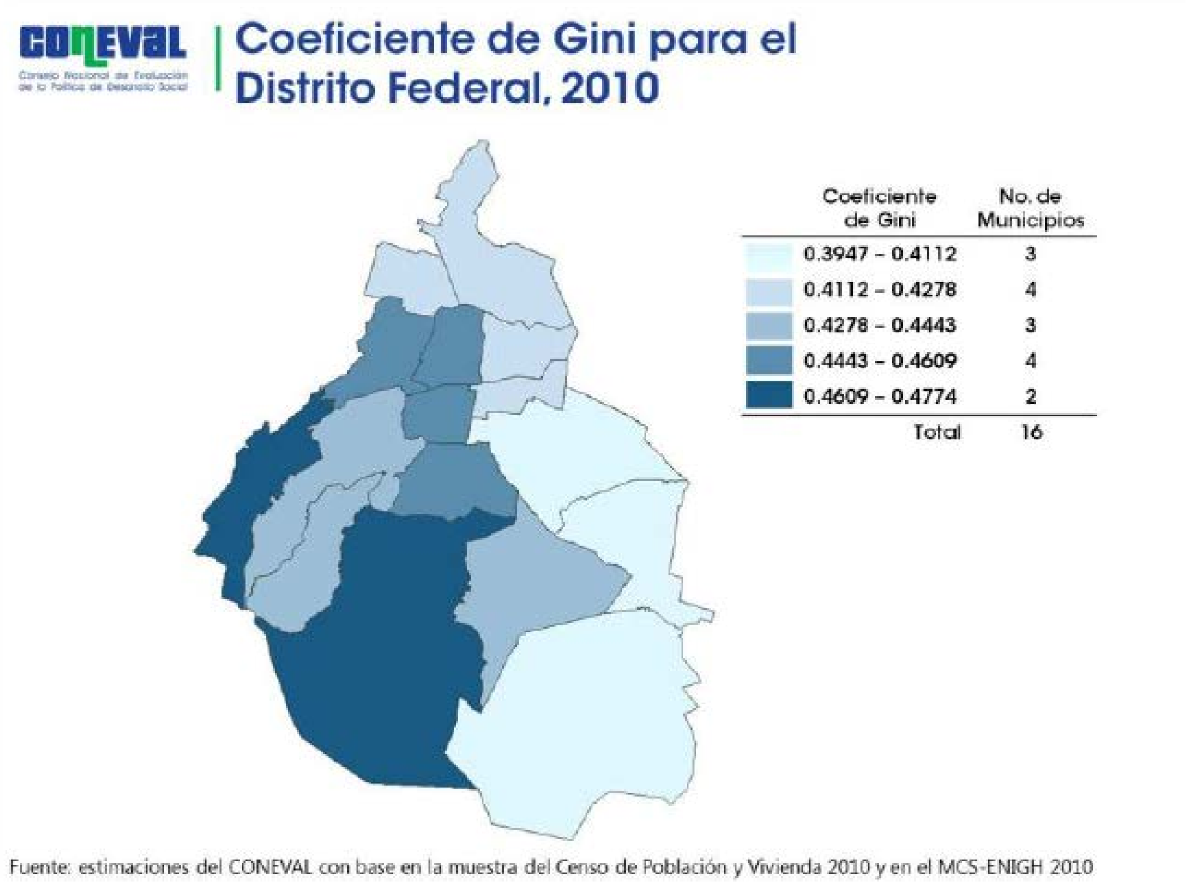

Figure A-3: Gini-index per borough of the Federal District (CONEVAL, 2012a).

APPENDIX C POLLUTANT DISTRIBUTION IN MCMA

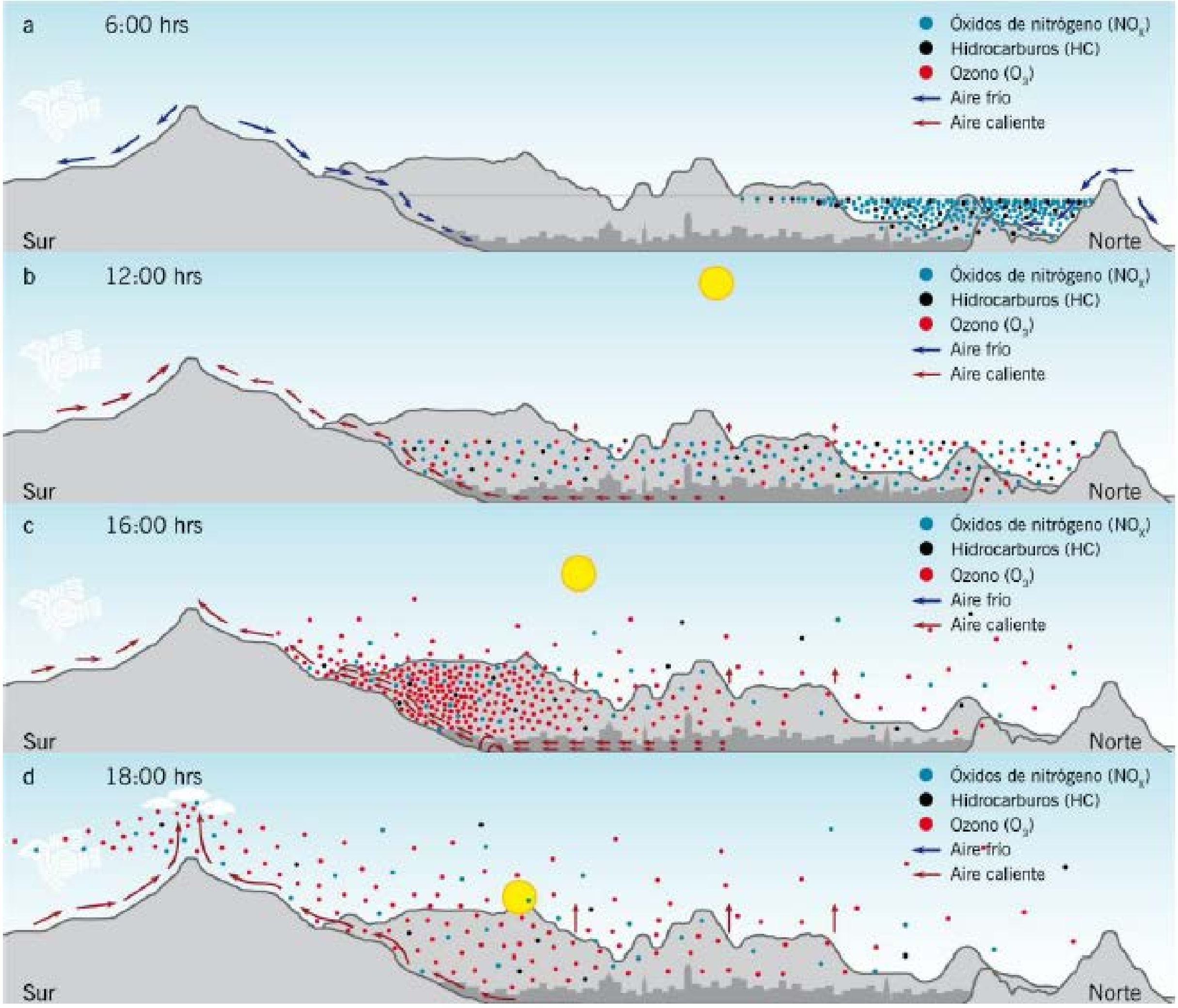

Figure A-4: Schematic depiction of the concentration of pollutants during the day in MCMA (Comisión Ambiental Metropolitana, 2011).

APPENDIX D PM$_{10}$ CONCENTRATIONS IN MEXICO CITY

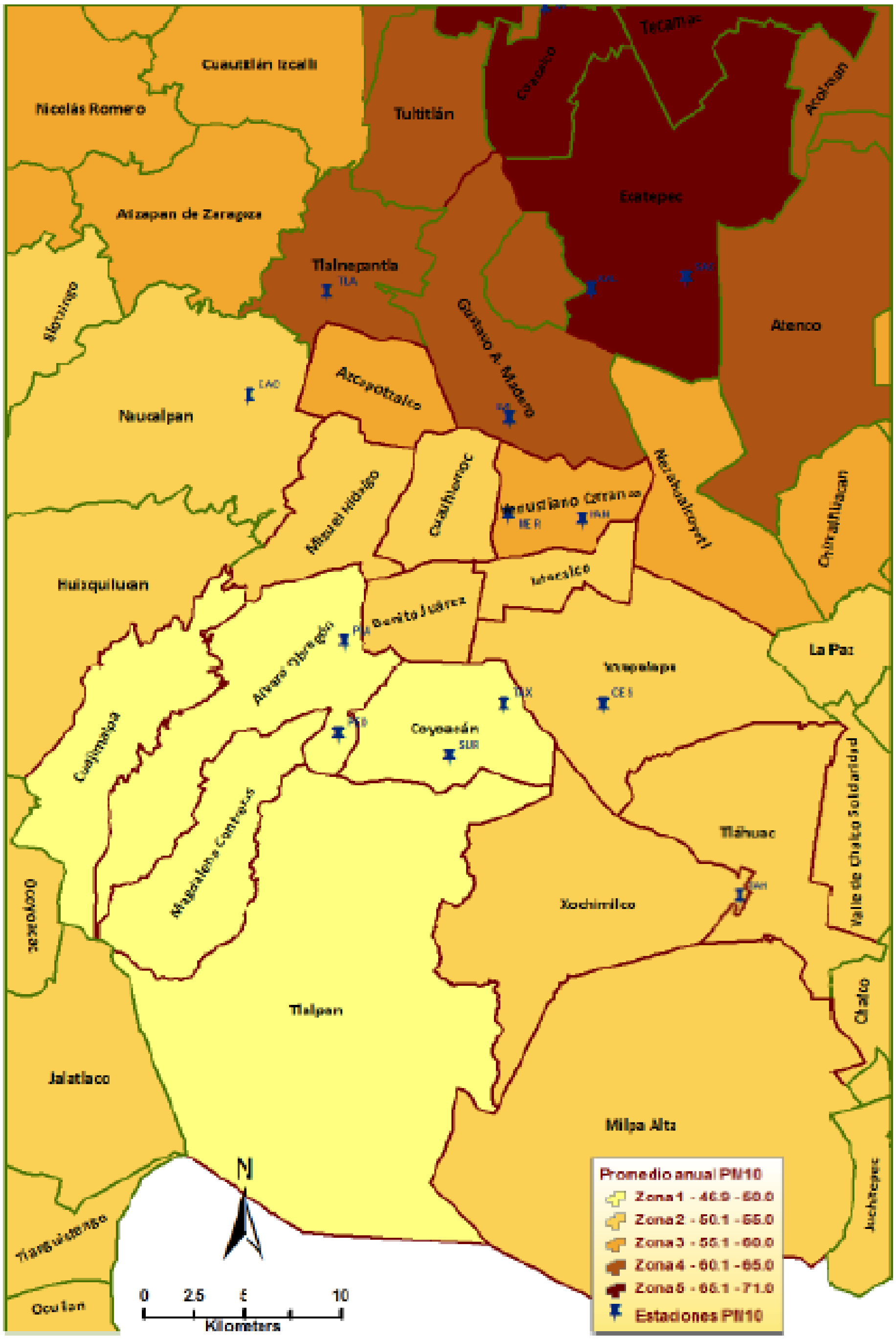

Figure A-5: Distribution of PM$_{10}$ concentrations in the MCMA (Comisión Ambiental Metropolitana, 2011).

APPENDIX E POLLUTANT CONCENTRATIONS DURING DAY

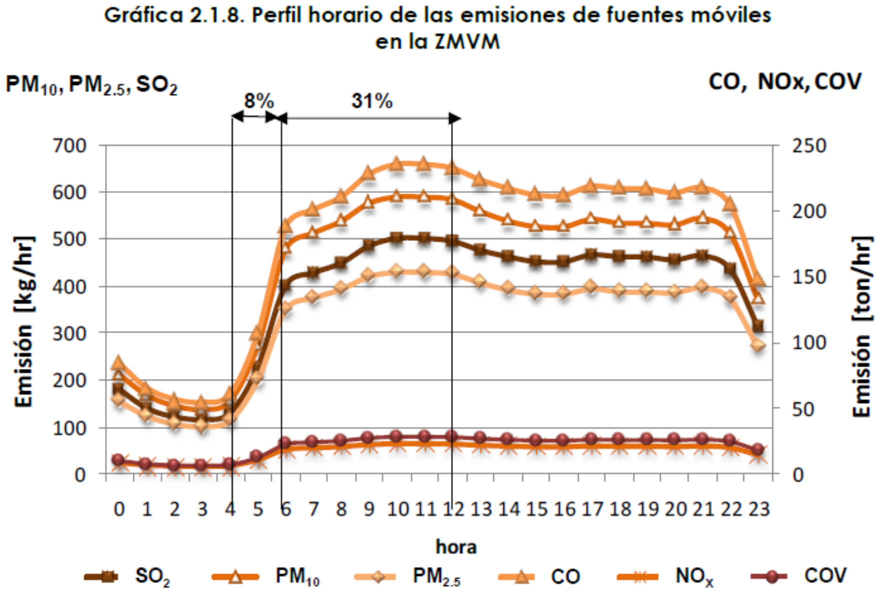

Figure A-6: Hourly profile of transport-based pollutant emissions in the MCMA (Comisión Ambiental Metropolitana, 2011).

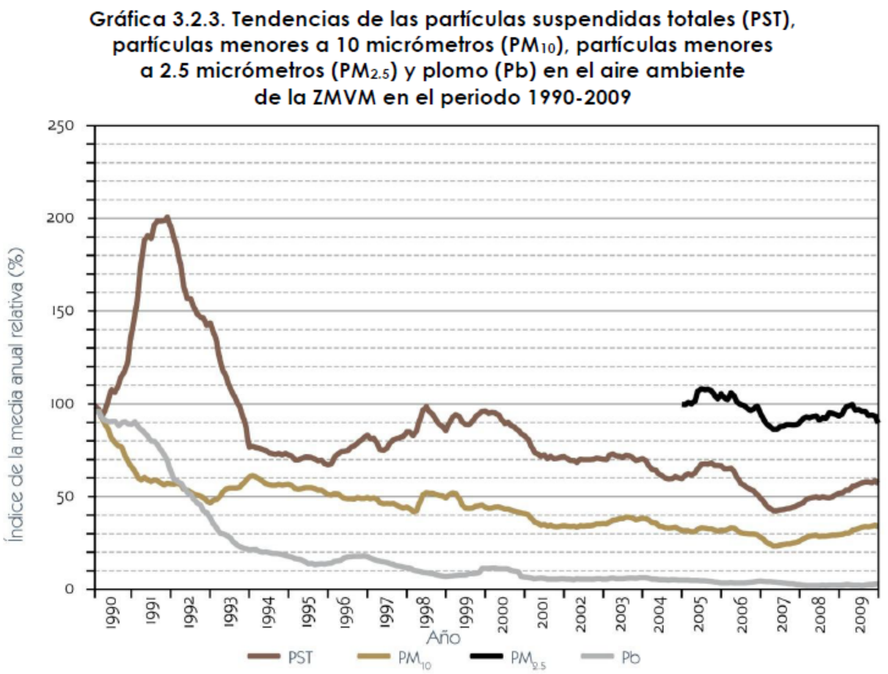

Figure A-7: Indexed pollutant concentrations over time (1990 index is 100) (Comisión Ambiental Metropolitana, 2011).

APPENDIX F NUMBER OF TRIPS DURING DAY

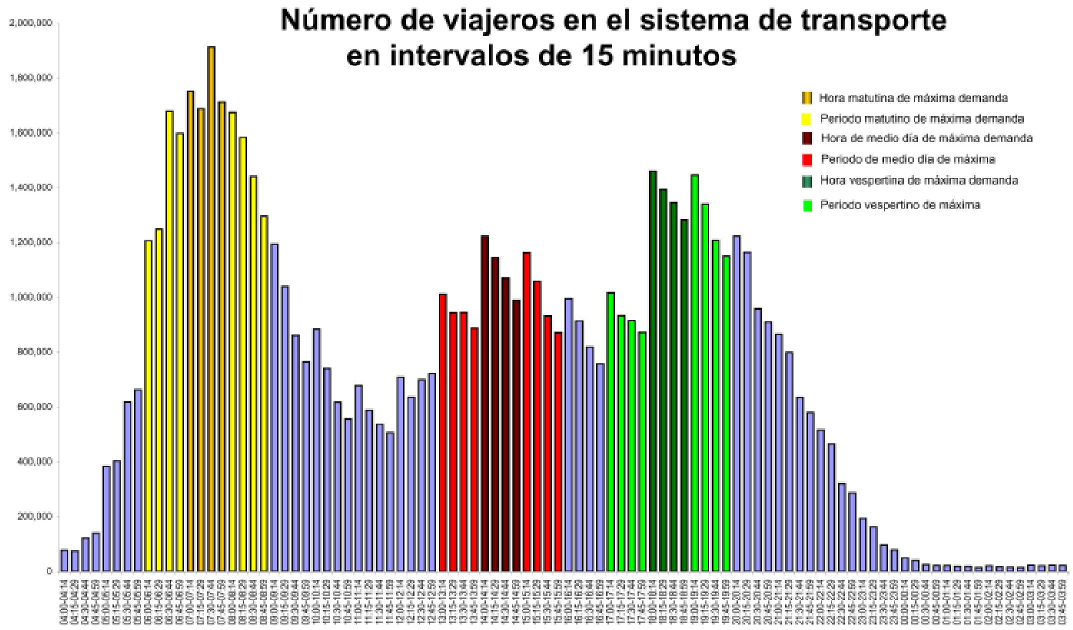

Figure A-8: Number of trips per 15 minutes in the MCMA (Ciudad de México, 2007).

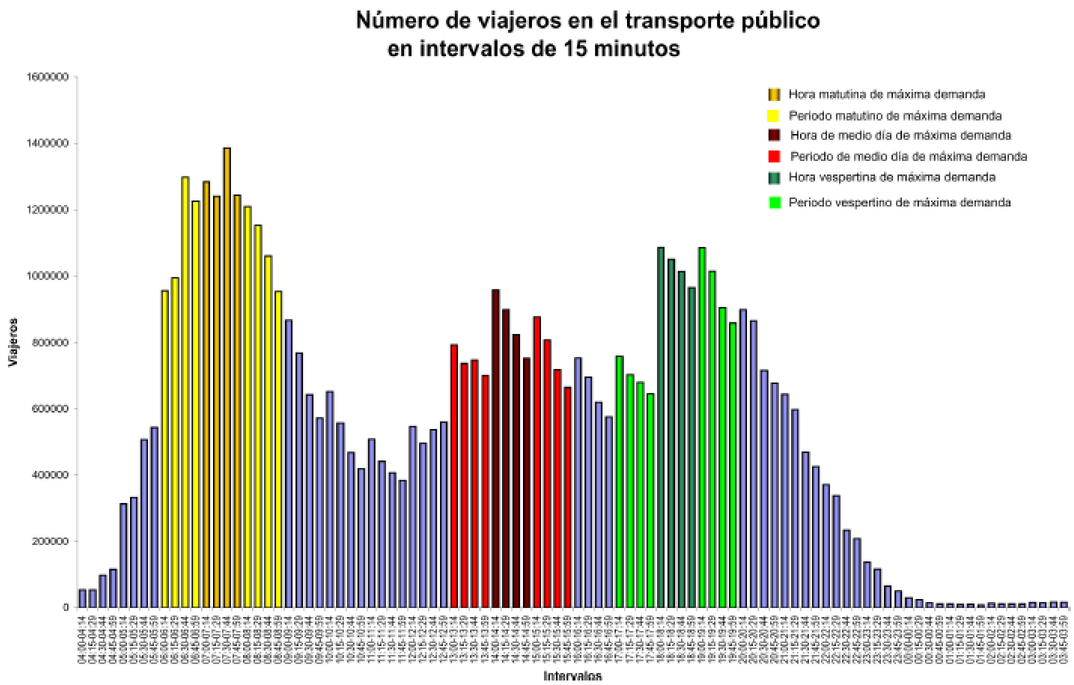

Figure A-9: Number of trips in public transport per 15 minutes in the MCMA (Ciudad de México, 2007).

APPENDIX G MAP METRO NETWORK

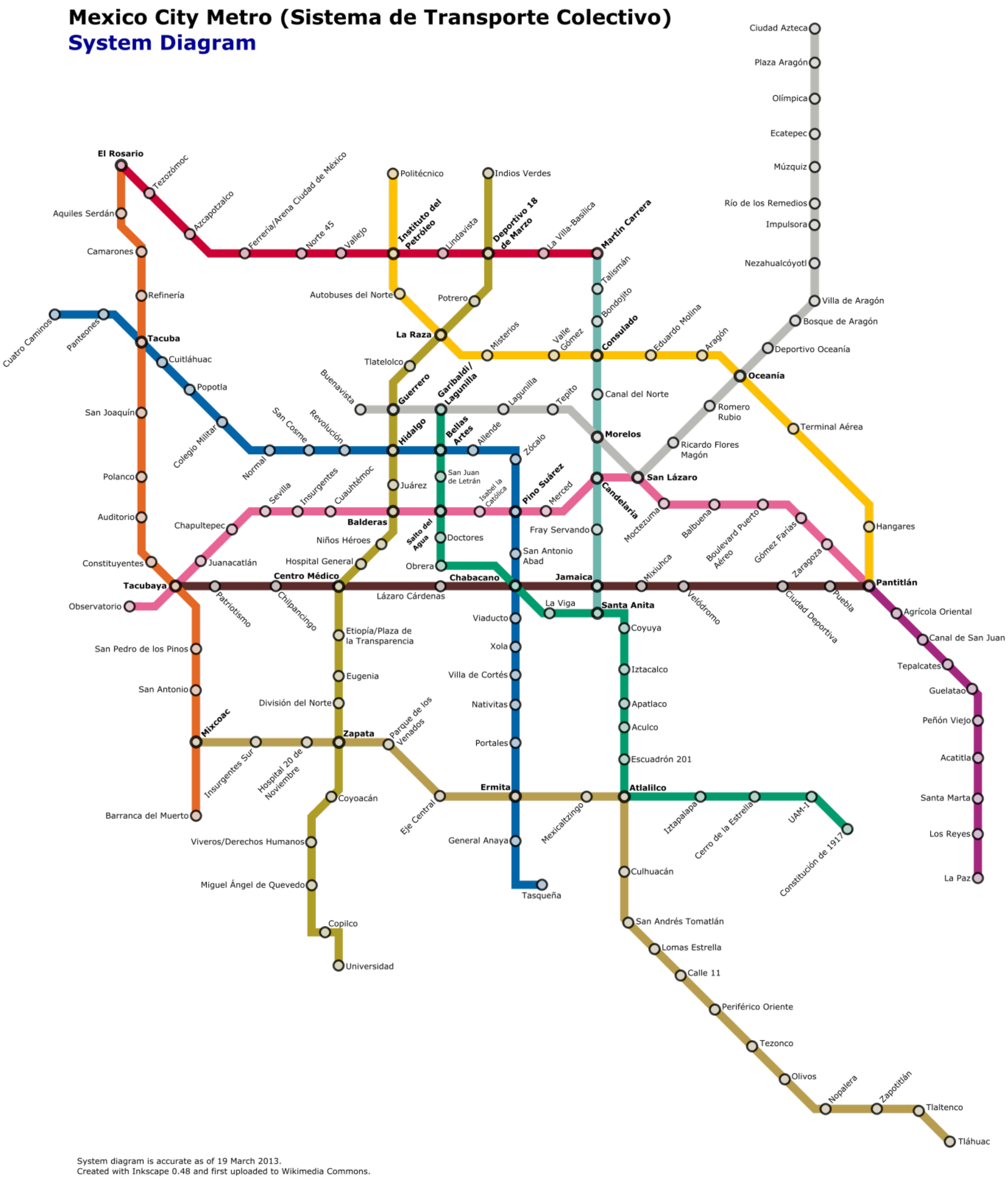

Figure A-10: Map of Mexico City's metro network (STC, 2013b).

APPENDIX H MAP METROBÚS NETWORK

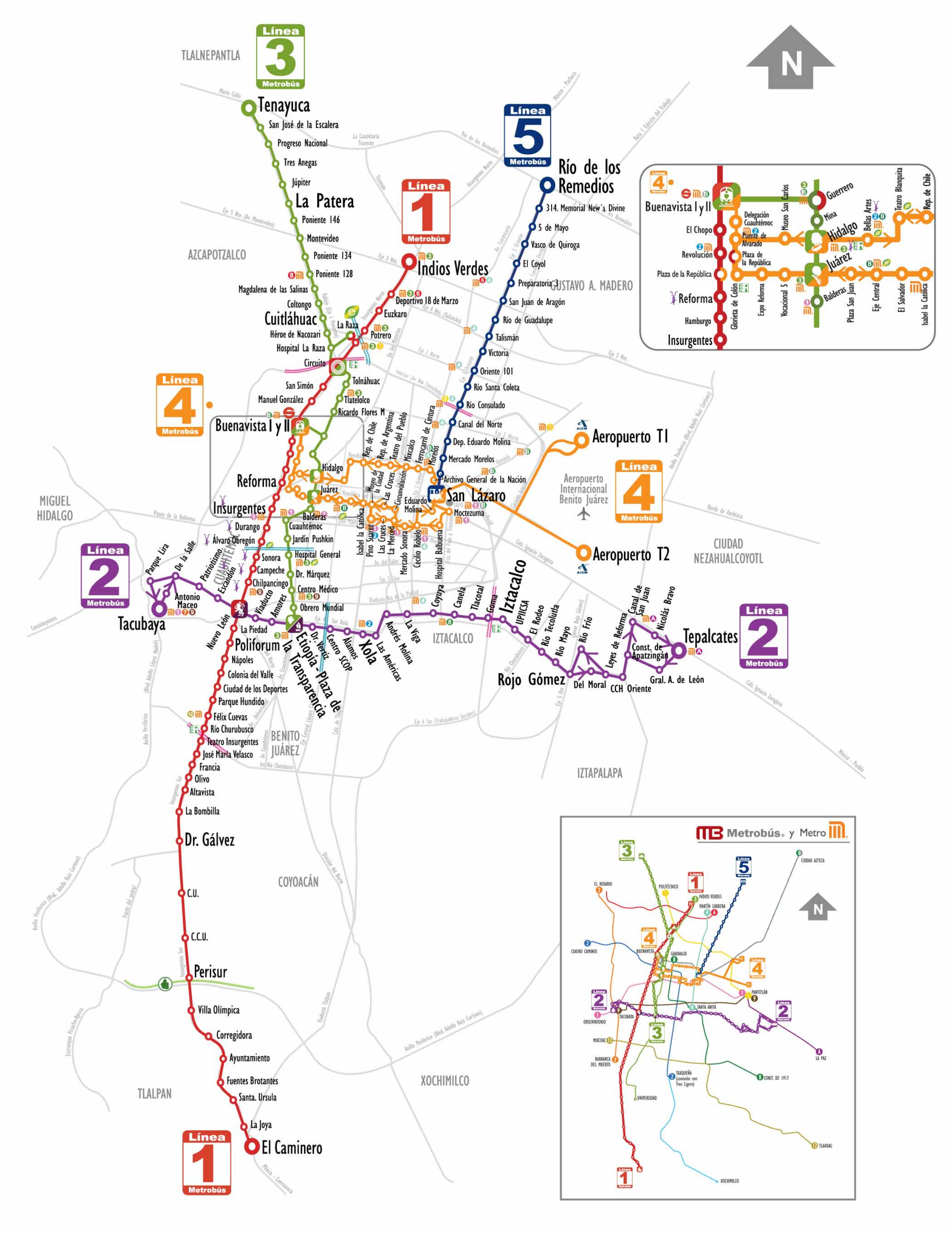

Figure A-11: Map of Mexico City's Metrobús network (Metrobús, 2013b).

APPENDIX I METROBÚS USER SURVEY

USUARIOS METROBÚS 2013				
Cuestionario No.	Encuestador	Supervisor	Codificador	Capturista

Fecha realización encuesta	DÍA		MES		A) Hora realización encuesta	H	H	M	M	B) Dia semana realización encuesta	L	M	Mi	J	V	S	D
											1	2	3	4	5	6	7

C) Estación dónde se realiza la encuesta

LÍNEA 1				LÍNEA 2				LÍNEA 3				LÍNEA 4			
1.	Indios Verdes	25.	Nápoles	48.	Tacubaya	72.	Río Tecolutla	84.	Tenayuca	108.	Juárez	117.	Buenavista	141.	El Salvador
2.	Deportivo 18 de Marzo	26.	Colonia del Valle	49.	Antonio Maceo	73.	Río Mayo	85.	Sn. José de la Escalera	109.	Balderas	118.	Delegación Cuauhtémoc	142.	Isabel la Catolica
3.	Euzkaro	27.	Ciudad de los Deportes	50.	Parque Lira	74.	Rojo Gómez	86.	Progreso Nacional	110.	Cuauhtémoc	119.	Puente de Alvarado	143.	Museo de la Ciudad
4.	Potrero	28.	Parque Hundido	51.	De La Salle	75.	Del Moral	87.	Tres Ánegas	111.	Jardín Pushkin	120.	Museo San Carlos	144.	Pino Suárez
5.	La Raza	29.	Félix Cuevas	52.	Patriotismo	76.	Río Frío	88.	Júpiter	112.	Hospital General	121.	Hidalgo	145.	Las Cruces
6.	Circuito	30.	Río Churubusco	53.	Escandón	77.	Leyes de Reforma	89.	La Patera	113.	Dr. Márquez	122.	Bellas Artes	146.	Circunvalan ción
7.	San Simón	31.	Teatro Insurgentes	54.	Nuevo León	78.	CCH Oriente	90.	Poniente 146	114.	Centro Médico	123.	Teatro Blanquita	147.	La Merced
8.	Manuel González	32.	José María Velasco	55.	Viaducto	79.	Contitucion de Apatzingan	91.	Montevideo	115.	Obrero Mundial	124.	Rep. De Chile	148.	Mercado Sonora
9.	Buenavista I	33.	Francia	56.	Amores	80.	Canal de San Juan	92.	Poniente 134	116.	Etiopía	125.	Rep. De Argentina	149.	Cecilio Robelo
10.	Buenavista II	34.	Olivo	57.	Etiopía	81.	Nicolás Bravo	93.	Poniente 128			126.	Teatro del Pueblo	150.	Eduardo Molina
11.	El Chopo	35.	Altavista	58.	Dr. Vértiz	82.	Gral. A de León	94.	Magdalena de las Salinas			127.	Mixcalco	151.	Hospital Balbuena
12.	Revolución	36.	La Bombilla	59.	Centro SCOP	83.	Tepalcates	95.	Coltongo			128.	FFCC de Cintura	152.	Moctezuma
13.	Plaza de la República	37.	Doctor Gálvez	60.	Álamos			96.	Cuitláhuac			129.	Morelos		
14.	Reforma	38.	C.U.	61.	Xola			97.	Héroe de Nacozari			130.	Archivo Gral. De la Nación		
15.	Hamburgo	39.	CCU	62.	Las Américas			98.	Hospital de La Raza			131.	San Lazaro (Terminal)		
16.	Insurgentes	40.	Perisur	63.	Andrés Molina			99.	La Raza I			132.	Aeropuerto Terminal 1		
17.	Durango	41.	Villa Olímpica	64.	La Viga			100.	Circuito			133.	Aeropuerto Terminal 2		
18.	Álvaro Obregón	42.	Corregidora	65.	Coyuya			101.	Tolnahuác			134.	Plaza de la Republica		
19.	Sonora	43.	Ayuntamient o	66.	Canela			102.	Tlatelolco			135.	Glorietade Colón		
20.	Campeche	44.	Fuentes Brotantes	67.	Tlacotal			103.	R. Flores Magón			136.	Expo Reforma		
21.	Chilpancingo	45.	Santa Úrsula	68.	Goma			104.	Guerrero			137.	Vocacional 5		
22.	Nuevo León	46.	La Joya	69.	Iztacalco			105.	Buenavista III			138.	Juárez		
23.	La Piedad	47.	El Caminero	70.	UPIICSA			106.	Mina			139.	Mercado de San Juan		
24.	Poliforum			71.	Rodeo			107.	Hidalgo			140.	Eje Central		

Buenos días/tardes: Mi nombre es....... y soy encuestador/a del Centro de Transporte Sustentable. Estamos haciendo una encuesta consultando su opinión acerca del servicio de Metrobús ¿Dispone de un momento para responder? Las respuestas son totalmente confidenciales. Muchas gracias.

SÍ ACEPTA ☐ 1 **NO ACEPTA** ☐ 2 ***(FIN DE LA ENTREVISTA)***

CARACTERIZACIÓN DEL VIAJE

1. ¿Cada cuándo acostumbra ud. usar el Metrobús?

Diariamente (5 a 7 veces por semana)	☐	1
Varias veces por semana (2 a 4 veces por semana)	☐	2
Algunas veces al mes (1 a 2 veces por mes)	☐	3
Casi nunca (menos de 1 vez por mes)	☐	4

2. ¿Tiene usted automóvil?

Sí	☐	1
No ***(PASA A PREG. 4)***	☐	2

3. ¿Me podría decir dónde dejó su auto el día de hoy, al usar Metrobús?

Estacionado	☐	1
Lo usó otra persona	☐	2
Descompuesto u otro	☐	3

4. ¿Cuál es el motivo del viaje en Metrobús?, ¿A dónde se dirige?
(ENCUESTADOR: SI RESPONDE QUE SE DIRIGE A SU CASA, PREGUNTAR DE DÓNDE VIENE)

Trabajo	☐	1
Escuela	☐	2
Comida	☐	3
Visita familiares/amigos	☐	4
Compras	☐	5
Esparcimiento (paseo/deporte)	☐	6
Médico	☐	7
Otra	☐	8

5. En este trayecto ¿En qué estación subió?

6. En este trayecto ¿En qué estación va a bajar?

LÍNEA 1

	P5.	P6.		P5.	P6.
Indios Verdes	1.	1.	Nápoles	25.	25.
Deportivo 18 de Marzo	2.	2.	Colonia del Valle	26.	26.
Euzkaro	3.	3.	Ciudad de los Deportes	27.	27.
Potrero	4.	4.	Parque Hundido	28.	28.
La Raza	5.	5.	Félix Cuevas	29.	29.
Circuito	6.	6.	Río Churubusco	30.	30.
San Simón	7.	7.	Teatro Insurgentes	31.	31.
Manuel González	8.	8.	José María Velasco	32.	32.
Buenavista I	9.	9.	Francia	33.	33.
Buenavista II	10.	10.	Olivo	34.	34.
El Chopo	11.	11.	Altavista	35.	35.
Revolución	12.	12.	La Bombilla	36.	36.
Plaza de la República	13.	13.	Doctor Gálvez	37.	37.
Reforma	14.	14.	C.U.	38.	38.
Hamburgo	15.	15.	CCU	39.	39.
Insurgentes	16.	16.	Perisur	40.	40.
Durango	17.	17.	Villa Olímpica	41.	41.
Álvaro Obregón	18.	18.	Corregidora	42.	42.
Sonora	19.	19.	Ayuntamiento	43.	43.
Campeche	20.	20.	Fuentes Brotantes	44.	44.
Chilpancingo	21.	21.	Santa Úrsula	45.	45.
Nuevo León	22.	22.	La Joya	46.	46.
La Piedad	23.	23.	El Caminero	47.	47.
Poliforum	24.	24.			

LÍNEA 2

	P5.	P6.		P5.	P6.
Tacubaya	48.	48.	Canela	66.	66.
Antonio Maceo	49.	49.	Tlacotal	67.	67.
Parque Lira	50.	50.	Goma	68.	68.
De La Salle	51.	51.	Iztacalco	69.	69.
Patriotismo	52.	52.	UPIICSA	70.	70.
Escandón	53.	53.	Rodeo	71.	71.
Nuevo León	54.	54.	Río Tecolutla	72.	72.
Viaducto	55.	55.	Río Mayo	73.	73.
Amores	56.	56.	Rojo Gómez	74.	74.
Etiopía	57.	57.	Del Moral	75.	75.
Dr. Vértiz	58.	58.	Río Frío	76.	76.
Centro SCOP	59.	59.	Leyes de Reforma	77.	77.
Álamos	60.	60.	CCH Oriente	78.	78.
Xola	61.	61.	Contitucion de Apatzingan	79.	79.
Las Américas	62.	62.	Canal de San Juan	80.	80.
Andrés Molina	63.	63.	Nicolás Bravo	81.	81.
La Viga	64.	64.	Gral. A de León	82.	82.
Coyuya	65.	65.	Tepalcates	83.	83.

LÍNEA 3

	P5.	P6.		P5.	P6.
Tenayuca	84.	84.	Tolnahuác	101.	101.
Sn. José de la Escalera	85.	85.	Tlatelolco	102.	102.
Progreso Nacional	86.	86.	R. Flores Magón	103.	103.
Tres Ánegas	87.	87.	Guerrero	104.	104.
Júpiter	88.	88.	Buenavista III	105.	105.
La Patera	89.	89.	Mina	106.	106.
Poniente 146	90.	90.	Hidalgo	107.	107.
Montevideo	91.	91.	Juárez	108.	108.

Poniente 134	92.	92.	Balderas	109.	109.
Poniente 128	93.	93.	Cuauhtémoc	110.	110.
Magdalena de las Salinas	94.	94.	Jardín Pushkin	111.	111.
Coltongo	95.	95.	Hospital General	112.	112.
Cuitláhuac	96.	96.	Dr. Márquez	113.	113.
Héroe de Nacozari	97.	97.	Centro Médico	114.	114.
Hospital de La Raza	98.	98.	Obrero Mundial	115.	115.
La Raza I	99.	99.	Etiopía	116.	116.
Circuito	100.	100.			
LÍNEA 4					
	P5.	**P6.**		**P5.**	**P6.**
Buenavista	117.	117.	Glorietade Colón	135.	135.
Delegación Cuauhtémoc	118.	118.	Expo Reforma	136.	136.
Puente de Alvarado	119.	119.	Vocacional 5	137.	137.
Museo San Carlos	120.	120.	Juárez	138.	138.
Hidalgo	121.	121.	Mercado de San Juan	139.	139.
Bellas Artes	122.	122.	Eje Central	140.	140.
Teatro Blanquita	123.	123.	El Salvador	141.	141.
Rep. De Chile	124.	124.	Isabel la Catolica	142.	142.
Rep. De Argentina	125.	125.	Museo de la Ciudad	143.	143.
Teatro del Pueblo	126.	126.	Pino Suárez	144.	144.
Mixcalco	127.	127.	Las Cruces	145.	145.
FFCC de Cintura	128.	128.	Circunvalanción	146.	146.
Morelos	129.	129.	La Merced	147.	147.
Archivo Gral. De la Nación	130.	130.	Mercado Sonora	148.	148.
San Lazaro (Terminal)	131.	131.	Cecilio Robelo	149.	149.
Aeropuerto Terminal 1	132.	132.	Eduardo Molina	150.	150.
Aeropuerto Terminal 2	133.	133.	Hospital Balbuena	151.	151.
Plaza de la Republica	134.	134.	Moctezuma	152.	152.

7 . Con la apertura de la línea 4, su modo de viajar en Metrobús ha...?

Mejorado	☐	1
Empeorado	☐	2
No lo he notado	☐	3

8. En una escala del 1 al 10, (donde 1 es el puntaje más bajo y el 10 el puntaje más alto), cuál es su opinión respecto a Metrobús en cuanto a...

a) La duración del tiempo de viaje	
b) La espera entre autobuses	
c) La comodidad del viaje	
d) La cantidad de autobuses	
e) La limpieza abordo de las unidades	
f) La comodidad abordo de las unidades	
g) La identifición de la ruta del autobús	
h) La limpieza en las estaciones	
i)El trato del personal a los pasajeros	
j) El trato de los policías al pasajero	
k) La forma de manejo de los conductores	
l) La señalización dentro de la estación	
m) Caminar a la estación de Metrobús	
n) La seguridad abordo del autobús	
o) La integridad física y moral en el autobús	

9. Por lo general, toma el primer autobús que viene o deja pasar...?

El primer autobús que viene	☐	1
Dejo pasar en promedio ________________ autobuses *(ANOTAR NUMERO)*	☐	2

10. ¿En el último mes, ha tenido problemas para recargar su tarjeta de Metrobús, cuántos? (*INDICAR CANTIDAD DE PROBLEMAS)*

No ha tenido problemas	☐	1
______________________*(ANOTAR NUMERO)*	☐	2

11. En relación con la calidad del servicio ¿El precio del Metrobús es barato, caro o aceptable?

Barato	☐	1
Caro	☐	2
Aceptable	☐	3
No sabe cómo calificarlo	☐	4

12. En su opinión...
(*LEER REACTIVO Y OPCIONES DE RESPUESTA SEPARARLAS POR UNA "O")*

a) Sería conveniente que se ampliara el servicio después de las 12 de la noche. (extendiendo su horario)	1.	Sí	2.	No
b) La temperatura en los autobuses es	1.	Confortable	2.	No confortable

SOLO LÍNEA 4 (PREGUNTAS 13 A 18)

13. ¿Qué modo de transporte utilizaba antes en el tramo de la línea 4 de Metrobús?

NO circulaba por ahí	☐	1
A pie	☐	2
Bicicleta	☐	3
Motocicleta	☐	4
Auto	☐	5
Taxi	☐	6

Autobuses de la Red de Transporte de Pasajeros (RTP)	☐	7
Combi / Micro / Autobús	☐	8
Trolebús	☐	9
Metro	☐	10
Metro y Micro	☐	11

14. Comparado con el modo de transporte que utilizaba su modo de viaje ha…?

Mejorado	☐	1
Empeorado	☐	2
No lo he notado	☐	3

15. Considerando todos los transportes que utiliza desde que salió hasta que llegue a su destino, ¿Cuánto va a pagar por su viaje completo actualmente? (puerta a puerta)

$____ ____ ____ ____.____ ____

16. Antes de la operación de la línea 4, ¿Cuánto pagaba por el mismo viaje?

$____ ____ ____ ____.____ ____

17. Considerando todos los transportes que utiliza desde que salió hasta que llegue a su destino, ¿Cuánto tiempo le lleva el viaje actualmente? (puerta a puerta)

____ ____ ____ ____ Minutos

18. Antes de la apertura de la línea 4, ¿Cuánto tiempo le llevaba el mismo viaje?

____ ____ ____ ____ Minutos

PREGUNTAR A TODOS

19. Comparándolo con otros modos de transporte, en su opinión ¿El servicio del Metrobús es mejor, igual o peor que…?

	Mejor	Igual	Peor	No lo usa
a. Los Taxis	1 ☐	2 ☐	3 ☐	4 ☐
b. La Red de Transporte de Pasajeros (RTP)	1 ☐	2 ☐	3 ☐	4 ☐
c. Combis, Microbuses, Autobuses	1 ☐	2 ☐	3 ☐	4 ☐
d. Los trolebuses	1 ☐	2 ☐	3 ☐	4 ☐
e. El tren ligero	1 ☐	2 ☐	3 ☐	4 ☐
f. El Metro	1 ☐	2 ☐	3 ☐	4 ☐
g. Tren Suburbano	1 ☐	2 ☐	3 ☐	4 ☐

20. Qué mejoraría en Metrobús?
(NO LEER LAS ALTERNATIVAS, QUE SEA ESPONTÁNEO Y ACEPTAR RESPUESTAS MÚLTIPLES)

Mayor frecuencia de unidades	☐	1
Mejor limpieza	☐	2
Mejor trato del personal	☐	3
Mejorar señalización	☐	6

Otro *(especificar)* ________________________________

Otro *(especificar)* ________________________________

Otro *(especificar)* ________________________________

21. Ud. Recomendaría el servicio de Metrobús?

Sí	☐	1
No	☐	2

22. Honestamente, En una escala del 1 al 10, donde 1 es peor y 10 mejor, Ud. califica al Metrobús en general con

____ ____ Puntos

CARACTERIZACIÓN DEL USUARIO

23. Sexo (*ANOTAR SIN PREGUNTAR)*

Masculino	☐	1
Femenino	☐	2

24. Discapacidad visible
(*ANOTAR SIN PREGUNTAR-RESPUESTA MÚLTIPLE)*

No tiene discapacidad	☐	1
Sí, tiene problemas en los brazos	☐	2
Sí, tiene problemas en las piernas (está en silla de ruedas)	☐	3
Sí, tiene problemas en las piernas (no está en silla de ruedas/usa bastón, muletas, etc.)	☐	4
Sí, tiene problemas de ceguera	☐	5
Sí, tiene otros problemas ***ESPECIFICAR***________________________________	☐	6

25. Qué edad tiene?

______________________ años

26. ¿A qué se dedica?

Desempleado	☐	1
Estudiante	☐	2
Ama de casa	☐	3
Jubilado/Otro/Inactivo	☐	4
Trabaja en Sector Público	☐	5
Trabaja en Sector Privado	☐	6
Trabaja por su cuenta	☐	7

27. ¿Hasta que nivel de estudios llegó usted?

Sin estudios	☐	1
Primaria	☐	2
Secundaria o Comercial	☐	3
Preparatoria, Bachillerato o Técnica	☐	4
Licenciatura	☐	5
Posgrado	☐	6

28. ¿Cuál es, aproximadamente, el ingreso mensual familiar? ***(LEER RANGOS)***		
De $1 a $1,500	☐	1
De $1,501 a $4,500	☐	2
De $4,501 a $7,500	☐	3
De $7,501 a $15,000	☐	4
De $15,001 a $30,000	☐	5
De $30,001 a $45,000	☐	6
De $45,001 a màs	☐	7

Muchas gracias!

Declaro que las informaciones por mi (Encuestador) recolectadas son verdaderas y fueron correctamente anotadas en el cuestionario y de acuerdo a las cuotas exigidas.

Firma: ___________________________________

APPENDIX J METROBÚS INTERVIEW QUESTIONS

a. ¿Cuánto es el pago por kilómetro a los operadores de la línea 4?
b. ¿Hubo manifestaciones en la construcción de la nueva línea? ¿Si es así, de quienes?
c. ¿Cómo trataron esas manifestaciones/resistencia?
d. ¿Se piensa que se han cumplido el objetivo para incentivar el uso del transporte público en lugar de los vehículos particulares? El número de gente que cambió del automóvil al Metrobús está suficiente?
e. ¿Se piensa que se han cumplido el objetivo para reducir en más de 40% los tiempos de recorrido?
f. ¿La implementación de la línea 4 ha integrado la operación con los demás modos de transporte masivo?
g. De los siguientes impactos: ahorros de tiempo recorrido, impactos ambientales e impactos sociales. ¿En su opinión, cuáles son los impactos más significativos de la línea 4?

APPENDIX K TRANSPORT SPECIALISTS INTERVIEW QUESTIONS

a. ¿En su opinión, cómo funciona el sistema de transporte en la Ciudad de México?
b. ¿Cómo podría mejorar el sistema de transporte? ¿Cuáles reformas son posibles?
c. Para este estudio, hemos desarrollado una herramienta de evaluación. Esta evaluación incluye los siguientes indicadores: seguridad (de accidentes), equidad, ahorros de tiempo, costos de construcción, costos de operación y mantenimiento, ingresos de venta de boletos, contaminación del aire, cambio climático y cambio modal. ¿De estos indicadores, cuáles considera los más importantes para evaluar los impactos de transporte en la Ciudad de México?
d. ¿En su opinión, faltan algunos indicadores? ¿Cuáles?
e. ¿Piensa que la evaluación de los impactos de proyectos en transporte público son de utilidad para la toma de decisiones políticas?
f. ¿En México, que aspecto es el más importante para tomar decisiones: aspectos políticos, económicos, sociales, medioambientales u otros?
g. ¿Cómo influye la elección del alcalde en las decisiones sobre la organización de transporte público?
h. ¿Cuándo se planea una nueva línea de transporte público, es necesario terminar la construcción antes de las próximas elecciones? ¿Sino, se corre el riesgo de no ser finiquitado por el próximo alcalde?
i. ¿Usted piensa que los mayores objetivos de la construcción de la línea 12 se han cumplido? ¿Y de la línea 4?

APPENDIX L METRO USER SURVEY

USUARIOS METRO 2013		
Cuestionario No.	Encuestador	Supervisor

(A) Fecha realización encuesta	DÍA		MES		B) Hora realización encuesta	H	H	M	M	C) Dia semana realización encuesta	L	M	Mi	J	V	S	D
											1	2	3	4	5	6	7

D) Estación dónde se empezó la encuesta			
LÍNEA 12			
1.	Mixcoac	11.	San Andrés Tomatlán
2.	Insurgentes Sur	12.	Lomas Estrella
3.	Hospital 20 Noviembre	13.	Calle 11
4.	Zapata	14.	Pereférico Oriente
5.	Parque de los Venados	15.	Tezonco
6.	Eje Central	16.	Olivos
7.	Ermita	17.	Nopalera
8.	Mexicaltzingo	18.	Zapotitlán
9.	Atlalilco	19.	Tlaltenco
10.	Culhuacán	20.	Tláhuac

E) Dirección del Metro	
DIRECCIÓN	
1.	Mixcoac
2.	Tláhuac

Buenos días/tardes: Mi nombre es....... y soy encuestador/a del Centro de Transporte Sustentable. Estamos haciendo una encuesta consultando su opinión acerca del servicio de Metro ¿Dispone de un momento para responder? Las respuestas son totalmente confidenciales. Muchas gracias.

SÍ ACEPTA ☐ 1 **NO ACEPTA** ☐ 2 ***(FIN DE LA ENTREVISTA)***

CARACTERIZACIÓN

1. ¿Cada cuándo acostumbra ud. usar el Metro?	
Diariamente (5 a 7 veces por semana)	☐ 1
Varias veces por semana (2 a 4 veces por semana)	☐ 2
Algunas veces al mes (1 a 2 veces por mes)	☐ 3
Casi nunca (menos de 1 vez por mes)	☐ 4

2. ¿Tiene usted automóvil?	
Sí	☐ 1
No	☐ 2

3. ¿Cuál es el motivo de este viaje en Metro?, ¿A dónde se dirige ahora? *(ENCUESTADOR: SI RESPONDE QUE SE DIRIGE A SU CASA, PREGUNTAR DE DÓNDE VIENE)*	
Trabajo	☐ 1
Escuela	☐ 2
Comida	☐ 3
Visita familiares/amigos	☐ 4
Compras	☐ 5
Esparcimiento (paseo/deporte)	☐ 6
Médico	☐ 7
Otra	☐ 8

4. En este trayecto ¿En qué línea y qué estación subió? (ANOTAR EN COLUMNO IZQUIERDO)

5. En este trayecto ¿En qué línea y qué estación va a bajar? (ANOTAR EN COLUMNO DERECHO)

LÍNEA 1					
	P4.	P5.		P4.	P5.
Observatorio	1.	1.	Pino Suárez	11.	11.
Tacubaya	2.	2.	Merced	12.	12.
Juanacatlán	3.	3.	Candelaria	13.	13.
Chapultepec	4.	4.	San Lázaro	14.	14.
Sevilla	5.	5.	Moctezuma	15.	15.

Insurgentes	6.	6.	Balbuena	16.	16.
Cuauhtémoc	7.	7.	Boulevard Puerto Aéreo	17.	17.
Balderas	8.	8.	Gómez Farías	18.	18.
Salto del Agua	9.	9.	Zaragoza	19.	19.
Isabel la Católica	10.	10.	Pantitlán	20.	20.
LÍNEA 2					
	P4.	**P5.**		**P4.**	**P5.**
Cuatro Caminos	21.	21.	Zócalo	33.	33.
Panteones	22.	22.	Pino Suárez	34.	34.
Tacuba	23.	23.	San Antonio Abad	35.	35.
Cuitláhuac	24.	24.	Chabacano	36.	36.
Popotla	25.	25.	Viaducto	37.	37.
Colegio Militar	26.	26.	Xola	38.	38.
Normal	27.	27.	Villa de Cortés	39.	39.
San Cosme	28.	28.	Nativitas	40.	40.
Revolución	29.	29.	Portales	41.	41.
Hidalgo	30.	30.	Ermita	42.	42.
Bellas Artes	31.	31.	General Anaya	43.	43.
Allende	32.	32.	Tasqueña	44.	44.
LÍNEA 3					
	P4.	**P5.**		**P4.**	**P5.**
Indios Verdes	45.	45.	Centro Médico	56.	56.
Deportivo 18 de Marzo	46.	46.	Etiopía/Plaza de la Transparencia	57.	57.
Potrero	47.	47.	Eugenia	58.	58.
La Raza	48.	48.	División del Norte	59.	59.
Tlatelolco	49.	49.	Zapata	60.	60.
Guerrero	50.	50.	Coyoacán	61.	61.
Hidalgo	51.	51.	Viveros/Derechos Humanos	62.	62.
Juárez	52.	52.	M.A. de Quevedo	63.	63.
Balderas	53.	53.	Copilco	64.	64.
Niños Héroes	54.	54.	Universidad	65.	65.
Hospital General	55.	55.			
LÍNEA 4					
	P4.	**P5.**		**P4.**	**P5.**
Martín Carrera	66.	66.	Morelos	71.	71.
Talismán	67.	67.	Candelaria	72.	72.
Bondojito	68.	68.	Fray Servando	73.	73.
Consulado	69.	69.	Jamaica	74.	74.
Canal del Norte	70.	70.	Santa Anita	75.	75.
LÍNEA 5					
	P4.	**P5.**		**P4.**	**P5.**
Politécnico	76.	76.	Eduardo Molina	83.	83.
Instituto del Petróleo	77.	77.	Aragón	84.	84.

Autobuses del Norte	78.	78.	Oceanía	85.	85.
La raza	79.	79.	Terminal Aérea	86.	86.
Misterios	80.	80.	Hangares	87.	87.
Valle Gómez	81.	81.	Pantitlán	88.	88.
Consulado	82.	82.			
LÍNEA 6					
	P4.	**P5.**		**P4.**	**P5.**
El Rosario	89.	89.	Instituto del Petróleo	95.	95.
Tezozómoc	90.	90.	Lindavista	96.	96.
Azcapotzalco	91.	91.	Deportivo 18 de Marzo	97.	97.
Ferrería/Arena Ciudad de México	92.	92.	La Villa-Basílica	98.	98.
Norte 45	93.	93.	Martín Carrera	99.	99.
Vallejo	94.	94.			
LÍNEA 7					
	P4.	**P5.**		**P4.**	**P5.**
El Rosario	100.	100.	Auditorio	107.	107.
Aquiles Serdán	101.	101.	Constituyentes	108.	108.
Camarones	102.	102.	Tacubaya	109.	109.
Refinería	103.	103.	San Pedro de los Pinos	110.	110.
Tacuba	104.	104.	San Antonio	111.	111.
San Joaquín	105.	105.	Mixcoac	112.	112.
Polanco	106.	106.	Barranca del Muerto	113.	113.
LÍNEA 8					
	P4.	**P5.**		**P4.**	**P5.**
Garibaldi/Lagunilla	114.	114.	Iztacalco	124.	124.
Bellas Artes	115.	115.	Apatlaco	125.	125.
San Juan de Letrán	116.	116.	Aculco	126.	126.
Salto del Agua	117.	117.	Escuadrón 201	127.	127.
Doctores	118.	118.	Atlalilco	128.	128.
Obrera	119.	119.	Iztapalapa	129.	129.
Chabacano	120.	120.	Cerro de la Estrella	130.	130.
La Viga	121.	121.	UAM-I	131.	131.
Santa Anita	122.	122.	Constitución de 1917	132.	132.
Coyuya	123.	123.			
LÍNEA 9					
	P4.	**P5.**		**P4.**	**P5.**
Tacubaya	133.	133.	Jamaica	139.	139.
Patriotismo	134.	134.	Mixiuhca	140.	140.
Chilpancingo	135.	135.	Velódromo	141.	141.
Centro Médico	136.	136.	Ciudad Deportiva	142.	142.
Lázaro Cárdenas	137.	137.	Puebla	143.	143.
Chabacano	138.	138.	Pantitlán	144.	144.

LÍNEA A (10)					
	P4.	P5.		P4.	P5.
Pantitlán	145.	145.	Peñón Viejo	150.	150.
Agrícola Oriental	146.	146.	Acatitla	151.	151.
Canal de San Juan	147.	147.	Santa Marta	152.	152.
Tepalcates	148.	148.	Los Reyes	153.	153.
Guelatao	149.	149.	La Paz	154.	154.

LÍNEA B (11)					
	P4.	P5.		P4.	P5.
Ciudad Azteca	155.	155.	Oceanía	166.	166.
Plaza Aragón	156.	156.	Romero Rubio	167.	167.
Olímpica	157.	157.	Ricardo Flores Magón	168.	168.
Ecatepec	158.	158.	San Lázaro	169.	169.
Múzquiz	159.	159.	Morelos	170.	170.
Río de los Remedios	160.	160.	Tepito	171.	171.
Impulsora	161.	161.	Lagunilla	172.	172.
Nezahualcóyotl	162.	162.	Garibaldi	173.	173.
Villa de Aragón	163.	163.	Guerrero	174.	174.
Bosque de Aragón	164.	164.	Buenavista	175.	175.
Deportivo Oceanía	165.	165.			

LÍNEA 12					
	P4.	P5.		P4.	P5.
Mixcoac	176.	176.	San Andrés Tomatlán	186.	186.
Insurgentes Sur	177.	177.	Lomas Estrella	187.	187.
Hospital 20 Noviembre	178.	178.	Calle 11	188.	188.
Zapata	179.	179.	Pereférico Oriente	189.	189.
Parque de los Venados	180.	180.	Tezonco	190.	190.
Eje Central	181.	181.	Olivos	191.	191.
Ermita	182.	182.	Nopalera	192.	192.
Mexicaltzingo	183.	183.	Zapotitlán	193.	193.
Atlalilco	184.	184.	Tlaltenco	194.	194.
Culhuacán	185.	185.	Tláhuac	195.	195.

6. En una escala del 1 al 10, (donde 1 es el puntaje más bajo y el 10 el puntaje más alto), cuál es su opinión respecto a seguridad de accidentes en Metro?

____ ____ Puntos

7. Antes de la apertura de la línea 12 ¿Qué modo de transporte utilizaba en el tramo de la línea 12 de Metro?

NO circulaba por ahí	☐	1
A pie	☐	2
Bicicleta	☐	3
Motocicleta	☐	4
Auto	☐	5
Taxi	☐	6
Autobuses de la Red de Transporte de Pasajeros (RTP)	☐	7
Combi / Micro / Autobús	☐	8
Trolebús	☐	9
Metro	☐	10
Metrobús	☐	11

8. En ese modo de transporte ¿Cuál era su opinión respecto a seguridad de accidentes?

____ ____ Puntos

9. Considerando todos los transportes que utiliza desde que salió hasta que llegue a su destino, ¿Cuánto tiempo le lleva el viaje actualmente? (puerta a puerta)

____ ____ ____ ____ Minutos

10. Antes de la apertura de la línea 12, ¿Cuánto tiempo le llevaba el mismo viaje?

____ ____ ____ ____ Minutos

CARACTERIZACIÓN DEL USUARIO

11. ¿Cuál es, aproximadamente, el ingreso mensual familiar?

(LEER RANGOS)

De $1 a $1,500	☐	1
De $1,501 a $4,500	☐	2
De $4,501 a $7,500	☐	3
De $7,501 a $15,000	☐	4
De $15,001 a $30,000	☐	5
De $30,001 a $45,000	☐	6
De $45,001 a màs	☐	7

12. Qué edad tiene?

____________________ años

13. ¿A qué se dedica?

Desempleado	☐	1
Estudiante	☐	2
Ama de casa	☐	3
Jubilado/Otro/Inactivo	☐	4
Trabaja en Sector Público	☐	5

Trabaja en Sector Privado	☐	6
Trabaja por su cuenta	☐	7

14. ¿Hasta que nivel de estudios llegó usted?		
Sin estudios	☐	1
Primaria	☐	2
Secundaria o Comercial	☐	3
Preparatoria, Bachillerato o Técnica	☐	4
Licenciatura	☐	5
Posgrado	☐	6

15. Sexo (*ANOTAR SIN PREGUNTAR)*		
Masculino	☐	1
Femenino	☐	2

Muchas gracias!

Declaro que las informaciones por mi (Encuestador) recolectadas son verdaderas y fueron correctamente anotadas en el cuestionario y de acuerdo a las cuotas exigidas.

Firma: ___________________________________

APPENDIX M METRO NON-USER SURVEY

NON-USUARIOS METRO 2013		
Cuestionario No.	Encuestador	Supervisor

A) Fecha realización encuesta	DÍA		MES		B) Hora realización encuesta	H	H	M	M	C) Dia semana realización encuesta	L	M	Mi	J	V	S	D
											1	2	3	4	5	6	7

D) Calle dónde se realiza la encuesta		E) Modo de transporte en el que se realiza la encuesta	
1.	Av. Tláhuac	1.	Bicicleta
2.	Eje 8 Sur (Calz. Ermita Iztapalapa) (entre Av. División del Norte y Av. Tláhuac)	2.	Motocicleta
3.	Av. División del Norte (entre Eje 7 Sur/Municipio Libre y Eje 8 Sur/Av. Popocatépetl)	3.	Auto
4.	Eje 7 Sur (entre Av. División del Norte y Av. Revolución)	4.	Taxi
		5.	Autobuses de la Red de Transporte de Pasajeros (RTP)
		6.	Combi / Micro / Autobús
		7.	Trolebús

Buenos días/tardes: Mi nombre es....... y soy encuestador/a del Centro de Transporte Sustentable. Estamos haciendo una encuesta consultando su caracterización del viaje ¿Dispone de un momento para responder? Las respuestas son totalmente confidenciales. Muchas gracias.

SÍ ACEPTA ☐ 1 **NO ACEPTA** ☐ 2 ***(FIN DE LA ENTREVISTA)***

CARACTERIZACIÓN DEL VIAJE

1. ¿Cuánto tiempo le lleva el viaje actualmente? (puerta a puerta)

____ ____ ____ ____ Minutos

2. Antes de la apertura de la línea 12 del Metro, ¿Cuánto tiempo le llevaba el mismo viaje?

____ ____ ____ ____ Minutos

3. ¿Cuál es el motivo de este viaje?, ¿A dónde se dirige?
(ENCUESTADOR: SI RESPONDE QUE SE DIRIGE A SU CASA, PREGUNTAR DE DÓNDE VIENE)

Trabajo	☐	1
Escuela	☐	2
Comida	☐	3
Visita familiares/amigos	☐	4
Compras	☐	5
Esparcimiento (paseo/deporte)	☐	6
Médico	☐	7
Otra	☐	8

4. En una escala del 1 al 10, (donde 1 es el puntaje más bajo y el 10 el puntaje más alto), cuál es su opinión respecto a seguridad de accidentes en este viaje?

____ ____ Puntos

5. Antes de la apertura de la línea 12 del Metro. ¿Cuál era su opinión respecto a seguridad de accidentes en el mismo viaje?

____ ____ Puntos

6. ¿Qué modo de transporte utilizaba antes de la apertura de la línea 12 de Metro?

NO circulaba por ahí	☐	1
A pie	☐	2
Bicicleta	☐	3
Motocicleta	☐	4
Auto	☐	5
Taxi	☐	6
Autobuses de la Red de Transporte de Pasajeros (RTP)	☐	7
Combi / Micro / Autobús	☐	8
Trolebús	☐	9
Metro	☐	10
Metrobús	☐	11

CARACTERIZACIÓN DEL RESPONDENTE

7. ¿Cuál es, aproximadamente, el ingreso mensual familiar?
(LEER RANGOS)

De $1 a $1,500	☐	1
De $1,501 a $4,500	☐	2
De $4,501 a $7,500	☐	3
De $7,501 a $15,000	☐	4
De $15,001 a $30,000	☐	5
De $30,001 a $45,000	☐	6
De $45,001 a más	☐	7

8. Qué edad tiene?

_____________________ años

9. ¿Hasta que nivel de estudios llegó usted?

Sin estudios	☐	1
Primaria	☐	2
Secundaria o Comercial	☐	3
Preparatoria, Bachillerato o Técnica	☐	4
Licenciatura	☐	5
Posgrado	☐	6

10. ¿A qué se dedica?

Desempleado	☐	1
Estudiante	☐	2
Ama de casa	☐	3
Jubilado/Otro/Inactivo	☐	4
Trabaja en Sector Público	☐	5
Trabaja en Sector Privado	☐	6
Trabaja por su cuenta	☐	7

11. Sexo (*ANOTAR SIN PREGUNTAR)*

Masculino	☐	1
Femenino	☐	2

Muchas gracias!

Declaro que las informaciones por mi (Encuestador) recolectadas son verdaderas y fueron correctamente anotadas en el cuestionario y de acuerdo a las cuotas exigidas.

Firma: ___________________________________

APPENDIX N EXPANSION FACTORS

N.1 METROBÚS USERS

Station	Passengers	Surveys	Expansion factor
Buenavista	9,440	14	674.27
Delegación Cuauhtemoc	683	11	62.08
Puente de Alvarado	1,742	10	174.21
Plaza de la República	905	9	100.52
Glorieta de Colón	2,461	10	246.13
Expo Reforma	1,307	10	130.66
Vocacional 5	1,059	10	105.91
Juárez	2,652	10	265.18
Plaza San Juán	1,881	10	188.07
Eje Central	2,770	10	276.98
El Salvador	1,075	10	107.54
Isabel la Católica	1,002	10	100.18
Museo de la Ciudad	1,229	9	136.61
Pino Suárez	358	10	35.83
Las Cruces	1,845	10	184.50
Circunvalanción	165	10	16.45
La Merced	394	10	39.36
Mercado de Sonora	568	10	56.77
Cecilo Robelo	472	10	47.24
Ing. Eduardo Molina	991	10	99.10
Hospital Balbuena	530	10	53.05
Moctezuma	862	15	57.50
San Lázaro	4,274	10	427.35
Aeropuerto T1	434	10	43.37
Aeropuerto T2	592	10	59.19
Archivo General de la Nación	1,785	10	178.48
Morelos	2,607	10	260.71
Ferrocarril de Cintura	2,527	11	229.77
Mixcalco	2,074	10	207.45
Teatro del Pueblo	3,443	10	344.26
República de Argentina	2,394	10	239.38
República de Chile	1,451	10	145.10
Teatro Blanquita	664	10	66.36
Bellas Artes	961	10	96.15
Hidalgo	1,275	10	127.53
Museo de San Carlos	472	10	47.22
Total	**59,344**	**369**	**-**

Table A-1: Expansion factors per boarding station of Metrobús line four.

N.2 METRO USERS

Station	Passengers		Surveys	Expansion factor
	Daily	Working day		
Tláhuac	37,228	46,536	69	674.43
Tlaltenco & Zapotitlán	14,166	17,707	19	931.97
Nopalera	14,949	18,686	18	1038.13
Olivos	13,950	17,438	10	1743.75
Tezonco	18,111	22,638	13	1741.40
Periférico Oriente	23,984	29,981	16	1873.79
Calle 11 & Lomas Estrella	21,118	26,398	13	2030.60
San Andrés Tomatlán & Culhuacán	21,185	26,482	15	1765.44
Atlalilco	10,264	12,830	18	712.80
Mexicaltzingo & Ermita	21,869	27,337	20	1366.83
Eje Central & Parque de los Venados	16,544	20,680	12	1723.32
Zapata	11,249	14,062	18	781.19

20 de Noviembre & Insurgentes Sur	33,825	42,281	16	2642.57
Mixcoac	11,343	14,179	48	295.40
Transfer passengers	160,213	200,267	69	2902.41
Total	**430,000**	**537,500**	**374**	**-**

Table A-2: Expansion factor per boarding station of Metro line twelve.

N.3 METROBÚS NON-USERS

Mode	Previous trips	Current trips	Surveys	Expansion factor
Metro	433,609	407,768	13	33,354.54
RTP	3,821	3,047	5	934.42
Micro/combi/autobús	102,026	75,445	79	934.42
Private modes	42,592	38,504	7	5,500.58
Metrobús	0	59,344	-	-
Total	**582,048**	**584,106**	**104**	**-**

Table A-3: Expansion factor per transport mode for Metrobús line four.

N.4 METRO NON-USERS

Mode	Previous trips	Current trips	Surveys	Expansion factor
Trolley bus	144,531	135,040	1	13,349.27
RTP	181,085	152,058	9	13,349.27
Micro/combi/autobús	669,084	326,968	36	13,349.27
Private modes	222,581	192,863	32	6,026.97
Metro	0	536,787	-	-
Total	**1,217,280**	**1,343,717**	**78**	**-**

Table A-4: Expansion factor per transport mode for Metro line twelve.

APPENDIX O LITERATURE VALUES CTVS

Indicator	Devillers et al. (2011)	Blonn et al. (2006)	Hidalgo et al. (2013)	Felipe Ochoa y Asociados (2012)	Spectron Desarrollo (2009)	Deng and Nelson (2013)	Breakthrough Technologies Institute (2012)
Project type	Tram	BRT	BRT	MRT	Metro	BRT	BRT
Appraisal period (years)		30	20	30	30		
Length (km)	7.5	13.20	84	19.3	24.5	15.8	
Equity							
Accidents		$23,100,000	$167,490,000	-51.0%			
Air pollution	+	$54,000,000	$114,450,000	13-51.1%	$11,147,287		
Climate change (ton CO_2/year)				-32,396			-40.0% -56.2% -41.0% -16.0% -44.0% -47.0% -65.0% -49.0% -83.0% -43.0% -65.0% -65.0%
Construction costs	$186,362,964	$130,300,000	$1,994,840,000	$367,286,524	$1,886,682,065	$79,000,000	
System operating and maintenance costs (per year)	$7,927,821	$18,800,000		$32,863,636	$35,085,407		
Operating revenues	$10,767,638	$14,900,000					
Travel time (hours)	641,000	-12.82%		-33.0%		-38.30%	-29%
Travel time savings (monetized)	€3,482,473	$70,200,000	$85,174,500	$53,043,713	$329,560,658		
Modal shift from car						12.40%	4.40%
Modal shift from taxi							
CO reduction (ton/year)				178.49			
NO_x reduction (ton/year)				47.99			
CO_2 reduction (ton/year)							
Trip generation						7.20%	
Operating costs (per km)	$1,057,043	$1,424,607		$1,702,779	$1,432,057		
Revenues (per year per km)	$1,435,685	$1,129,077					
Construction costs (per km)	$24,848,395	$9,873,740	$23,748,095	$19,030,390	$77,007,431	$5,000,000	

Indicator	Vincent and Callaghan (2007)	Lin and Wu (2007)	Alpkokin and Ergun (2012)	Hidalgo and Gutiérrez (2013)	Instituto Nacional de Ecología (2006)	Doll and Balaban (2013)		Litman (2012)
Project type	BRT	BRT	BRT	BRT	BRT	Metro	Potential	Rail
Appraisal period (years)					10			
Length (km)	22.5	16	42		20	190	190	
Equity			>50% low income >50% no car					
Accidents								-35.9%
Air pollution								
Climate change (ton CO_2/year)			-60,955		-24,364	-2.3%	-9.3%	
Construction costs	$350,000,000	$99,608,030			$44,380,000			
System operating and maintenance costs (per year)	0.54 USD/PKT		3.56 USD/VKT					
Operating revenues			4.75 USD/VKT					
Travel time (hours)	-14%				-29.1%			
Travel time savings (monetized)								
Modal shift from car	18%		9%		6.40%	6.3%	12.5%	
Modal shift from taxi						22.3%	44.6%	
CO reduction (ton/year)						-6,545	-13,089	
NO_x reduction (ton/year)						-1,443	-2,887	
CO_2 reduction (ton/year)						-115,658	-463,444	
Trip generation								
Operating costs (per km)								
Revenues (per year per km)								
Construction costs (per km)	$15,534,280	$6,225,502		$2,400,000 $3,600,000 $12,500,000 $3,500,000 $1,800,000 $1,400,000 $2,800,000 $4,800,000 $5,700,000 $2,000,000 $3,800,000 $2,400,000	$2,219,000			

Indicator	Monzón et al. (2013)	NYC Global Partners (2012)	PROPOLIS (2004)	Thomopoulos and Grant-Muller (2013)	Turner et al. (2012)	Madison Area Transportation Planning Board (2013)	ALC-BRT and EMBARQ (2013)	Duduta et al. (2012)
Project type	Rail	BRT	PT speed +10%	Infrastructure improvement	BRT	BRT	BRT	BRT
Appraisal period (years)			20					
Length (km)		67			84	20.29		
Equity	23.1%		4.55%	-1.8%				
Accidents		-30%	-1.52%					-20.0% -46.0% -60.0%
Air pollution		-71.4%	-22.22%		-12.0%			
Climate change (ton CO_2/year)			-4.24%					
Construction costs								
System operating and maintenance costs (per year)						$18,500,000		
Operating revenues						$1,758,000		
Travel time (hours)			-1.65%		-32.0%			
Travel time savings (monetized)								
Modal shift from car		15%						14.00%
Modal shift from taxi								
CO reduction (ton/year)								
NO_x reduction (ton/year)								
CO_2 reduction (ton/year)								
Trip generation								
Operating costs (per km)						$911,892		
Revenues (per year per km)							$2,575,000	
Construction costs (per km)								

Indicator	Flyvbjerg et al. (2008)			Levinson et al. (2003)	
Project type	Metro			BRT	
Appraisal period (years)					
Length (km)					
Equity					
Accidents					
Air pollution					
Climate change (ton CO_2/year)					
Construction costs					
System operating and maintenance costs (per year)					
Operating revenues					
Travel time (hours)				-20.0% -42.0% -20% -18.9%	-33.0% -38.0% -32.0% -29.0%
Travel time savings (monetized)					
Modal shift from car					
Modal shift from taxi					
CO reduction (ton/year)					
NO_x reduction (ton/year)					
CO_2 reduction (ton/year)					
Trip generation					
Operating costs (per km)					
Revenues (per year per km)				$2,156,818 $728,000 $129,747 $240,000	$170,000 $362,353 $2,068,333
Construction costs (per km)	$69,800,000 $329,900,000 $26,700,000 $60,900,000 $81,100,000 $59,100,000 $5,600,000 $79,500,000 $220,000,000 $68,800,000	$88,300,000 $16,100,000 $56,900,000 $71,700,000 $114,300,000 $88,000,000 $147,500,000 $131,600,000 $126,900,000 $94,200,000	$109,400,000 $54,500,000 $65,800,000 $59,900,000 $43,800,000 $98,400,000 $71,800,000 $63,200,000 $63,100,000	$19,642,857 $6,510,417 $5,518,018 $4,496,951 $5,174,629 $16,110,248	$5,797,297 $15,714,286 $4,342,105 $669,643 $4,872,881 $3,600,000

Table A-5: Literature values applicable to CTVs.

APPENDIX P DIRECT AND INDIRECT TTS METROBÚS

Income group (MEX$)	Daily trips	Trips (%)	Annual TTS (hours)	TTS (%)	Annual TTS (US$)	Monetized TTS (%)
$0 - $1,500	8,541	14.4%	639,211	13.4%	$105,470	1.3%
$1,501 - $4,500	16,027	27.0%	1,368,433	28.6%	$903,166	10.8%
$4,501 - $7,500	14,516	24.5%	1,311,626	27.5%	$1,731,346	20.8%
$7,501 - $15,000	13,740	23.2%	1,010,235	21.1%	$2,500,331	30.0%
$15,001 - $30,000	3,844	6.5%	181,682	3.8%	$899,506	10.8%
$30,001 - $45,000	2,675	4.5%	265,457	5.6%	$2,190,282	26.3%
More than $45,000	0	0.0%	0	0.0%	$0	0.0%
Total	**59,344**	**100.0%**	**4,776,642**	**100.0%**	**$8,330,100**	**100.0%**
Average per trip (minutes)	**-**	**-**	**16.5**	**34.7%**	**$0.48**	**31.3%**
Equity VOT	**59,344**	**100.0%**	**4,776,642**	**24.5%**	**$17,964,952**	**24.5%**[1]

Table A-6: Direct travel time savings for Metrobús.

Income group (MEX$)	Daily trips	Trips (%)	Annual TTS (hours)	TTS (%)	Annual TTS (US$)	Monetized TTS (%)
$0 - $1,500	50,174	9.1%	227,376	1.5%	$37,517	0.3%
$1,501 - $4,500	364,136	66.1%	8,601,992	58.6%	$5,677,314	40.4%
$4,501 - $7,500	99,202	18.0%	5,630,559	38.3%	$7,432,338	52.9%
$7,501 - $15,000	36,158	6.6%	90,950	0.6%	$225,102	1.6%
$15,001 - $30,000	934	0.2%	136,426	0.9%	$675,443	4.8%
$30,001 - $45,000	0	0.0%	0	0.0%	$0	0.0%
More than $45,000	0	0.0%	0	0.0%	$0	0.0%
Total	**550,604**	**100.0%**	**14,687,303**	**100.0%**	**$14,047,715**	**100.0%**
Average per trip (minutes)	**-**	**-**	**5.5**	**9.1%**	**$0.09**	**10.5%**
Equity VOT	**550,604**	**100.0%**	**14,687,303**	**75.5%**	**$55,238,945**	**75.5%**[1]

Table A-7: Indirect travel time savings for Metrobús.

[1] Percentage of total travel time savings

APPENDIX Q DIRECT AND INDIRECT TTS METRO

Income group (MEX$)	Daily trips	Trips (%)	Annual TTS (hours)	TTS (%)	Annual TTS (US$)	Monetized TTS (%)
$0 - $1,500	116,970	21.8%	13,993,072	20.3%	$2,308,857	3.5%
$1,501 - $4,500	222,307	41.4%	30,910,730	44.8%	$20,401,082	31.2%
$4,501 - $7,500	133,771	24.9%	17,286,766	25.0%	$22,818,531	34.9%
$7,501 - $15,000	55,631	10.4%	5,980,244	8.7%	$14,801,104	22.7%
$15,001 - $30,000	5,206	1.0%	658,385	1.0%	$3,259,664	5.0%
$30,001 - $45,000	2,902	0.5%	211,876	0.3%	$1,748,191	2.7%
More than $45,000	0	0.0%	0	0.0%	$0	0.0%
Total	**536,787**	**100.0%**	**69,041,074**	**100.0%**	**$65,337,429**	**100.0%**
Average per trip (minutes)	**-**	**-**	**26.4**	**27.1%**	**$0.42**	**27.2%**
Equity VOT	**536,787**	**100.0%**	**69,041,074**	**66.6%**	**$259,663,478**	**66.6%**[1]

Table A-8: Direct travel time savings for Metro.

Income group (MEX$)	Daily trips	Trips (%)	Annual TTS (hours)	TTS (%)	Annual TTS (US$)	Monetized TTS (%)
$0 - $1,500	32,726	4.1%	1,494,228	4.3%	$246,548	0.6%
$1,501 - $4,500	419,405	52.0%	17,099,662	49.4%	$11,285,777	26.2%
$4,501 - $7,500	227,783	28.2%	9,377,671	27.1%	$12,378,526	28.7%
$7,501 - $15,000	70,183	8.7%	5,522,147	16.0%	$13,667,315	31.7%
$15,001 - $30,000	44,779	5.5%	1,121,153	3.2%	$5,550,827	12.9%
$30,001 - $45,000	6,027	0.7%	0	0.0%	$0	0.0%
More than $45,000	6,027	0.7%	0	0.0%	$0	0.0%
Total	**806,929**	**100.0%**	**34,614,861**	**100.0%**	**$43,128,992**	**100.0%**
Average per trip (minutes)	**-**	**-**	**8.8**	**15.6%**	**$0.18**	**14.7%**
Equity VOT	**806,929**	**100.0%**	**34,614,861**	**33.4%**	**$130,186,493**	**33.4%**[1]

Table A-9: Indirect travel time savings for Metro.

[1] Percentage of total travel time savings

APPENDIX R ECONOMIC AGGREGATION METROBÚS

Year	Construction costs (US$)	Operating & maintenance costs (US$/year)	Revenues (US$/year)	Travel time savings (US$)	Net present value (US$)
0	-$41,128,909	$0	$0	$0	-$41,128,909
1	$0	-$4,395,292	$6,603,317	$66,738,529	$27,817,645
2	$0	-$3,867,857	$5,810,919	$60,844,182	$90,604,889
3	$0	-$3,403,714	$5,113,609	$55,470,424	$147,785,207
4	$0	-$2,995,269	$4,499,976	$50,571,276	$199,861,190
5	$0	-$2,635,836	$3,959,979	$46,104,821	$247,290,154
6	$0	-$2,319,536	$3,484,781	$42,032,843	$290,488,242
7	$0	-$2,041,192	$3,066,608	$38,320,502	$329,834,160
8	$0	-$1,796,249	$2,698,615	$34,936,036	$365,672,562
9	$0	-$1,580,699	$2,374,781	$31,850,485	$398,317,129
10	$0	-$1,391,015	$2,089,807	$29,037,450	$428,053,371
11	$0	-$1,224,093	$1,839,030	$26,472,863	$455,141,171
12	$0	-$1,077,202	$1,618,347	$24,134,779	$479,817,095
13	$0	-$947,938	$1,424,145	$22,003,196	$502,296,498
14	$0	-$834,185	$1,253,248	$20,059,873	$522,775,434
15	$0	-$734,083	$1,102,858	$18,288,185	$541,432,394
Total	**-$41,128,909**	**-$31,244,160**	**$46,940,019**	**$566,865,444**	**$541,432,394**
B/C ratio	**-**	**-**	**-**	**-**	**8.48**

Table A-10: Economic aggregation for Metrobús using equity VOT.

Year	Construction costs (US$)	Operating & maintenance costs (US$/year)	Revenues (US$/year)	Travel time savings (US$)	Net present value (US$)
0	-$41,128,909	$0	$0	$0	-$41,128,909
1	$0	-$4,395,292	$6,603,317	$20,401,406	-$18,519,478
2	$0	-$3,867,857	$5,810,919	$18,599,554	$2,023,138
3	$0	-$3,403,714	$5,113,609	$16,956,841	$20,689,874
4	$0	-$2,995,269	$4,499,976	$15,459,213	$37,653,794
5	$0	-$2,635,836	$3,959,979	$14,093,855	$53,071,792
6	$0	-$2,319,536	$3,484,781	$12,849,086	$67,086,123
7	$0	-$2,041,192	$3,066,608	$11,714,255	$79,825,794
8	$0	-$1,796,249	$2,698,615	$10,679,652	$91,407,812
9	$0	-$1,580,699	$2,374,781	$9,736,425	$101,938,319
10	$0	-$1,391,015	$2,089,807	$8,876,504	$111,513,615
11	$0	-$1,224,093	$1,839,030	$8,092,531	$120,221,083
12	$0	-$1,077,202	$1,618,347	$7,377,799	$128,140,027
13	$0	-$947,938	$1,424,145	$6,726,192	$135,342,426
14	$0	-$834,185	$1,253,248	$6,132,134	$141,893,622
15	$0	-$734,083	$1,102,858	$5,590,544	$147,852,942
Total	**-$41,128,909**	**-$31,244,160**	**$46,940,019**	**$173,285,992**	**$147,852,942**
B/C ratio	**-**	**-**	**-**	**-**	**3.04**

Table A-11: Economic aggregation for Metrobús using income-dependent VOT.

APPENDIX S ECONOMIC AGGREGATION METRO

Year	Construction costs (US$)	Operating & maintenance costs (US$/year)	Revenues (US$/year)	Travel time savings (US$)	Net present value (US$)
0	-$1,613,409,611	$0	$0	$0	-$1,613,409,611
1	$0	-$37,384,118	$43,641,939	$355,418,421	-$1,251,733,369
2	$0	-$32,898,023	$38,404,906	$324,027,866	-$922,198,620
3	$0	-$28,950,261	$33,796,317	$295,409,725	-$621,942,839
4	$0	-$25,476,229	$29,740,759	$269,319,138	-$348,359,171
5	$0	-$22,419,082	$26,171,868	$245,532,872	-$99,073,513
6	$0	-$19,728,792	$23,031,244	$223,847,408	$128,076,348
7	$0	-$17,361,337	$20,267,495	$204,077,205	$335,059,711
8	$0	-$15,277,977	$17,835,395	$186,053,107	$523,670,236
9	$0	-$13,444,619	$15,695,148	$169,620,896	$695,541,661
10	$0	-$11,831,265	$13,811,730	$154,639,979	$852,162,105
11	$0	-$10,411,513	$12,154,323	$140,982,176	$994,887,090
12	$0	-$9,162,132	$10,695,804	$128,530,630	$1,124,951,392
13	$0	-$8,062,676	$9,412,307	$117,178,805	$1,243,479,828
14	$0	-$7,095,155	$8,282,830	$106,829,573	$1,351,497,077
15	$0	-$6,243,736	$7,288,891	$97,394,385	$1,449,936,616
Total	**-$1,613,409,611**	**-$265,746,915**	**$310,230,957**	**$3,018,862,185**	**$1,449,936,616**
B/C ratio	**-**	**-**	**-**	**-**	**1.77**

Table A-12: Economic aggregation for Metro using equity VOT.

Year	Construction costs (US$)	Operating & maintenance costs (US$/year)	Revenues (US$/year)	Travel time savings (US$)	Net present value (US$)
0	-$1,613,409,611	$0	$0	$0	-$1,613,409,611
1	$0	-$37,384,118	$43,641,939	$98,886,667	-$1,508,265,123
2	$0	-$32,898,023	$38,404,906	$90,152,996	-$1,412,605,244
3	$0	-$28,950,261	$33,796,317	$82,190,684	-$1,325,568,504
4	$0	-$25,476,229	$29,740,759	$74,931,603	-$1,246,372,371
5	$0	-$22,419,082	$26,171,868	$68,313,643	-$1,174,305,942
6	$0	-$19,728,792	$23,031,244	$62,280,182	-$1,108,723,307
7	$0	-$17,361,337	$20,267,495	$56,779,597	-$1,049,037,553
8	$0	-$15,277,977	$17,835,395	$51,764,823	-$994,715,311
9	$0	-$13,444,619	$15,695,148	$47,192,954	-$945,271,829
10	$0	-$11,831,265	$13,811,730	$43,024,872	-$900,266,492
11	$0	-$10,411,513	$12,154,323	$39,224,915	-$859,298,768
12	$0	-$9,162,132	$10,695,804	$35,760,571	-$822,004,525
13	$0	-$8,062,676	$9,412,307	$32,602,197	-$788,052,696
14	$0	-$7,095,155	$8,282,830	$29,722,771	-$757,142,249
15	$0	-$6,243,736	$7,288,891	$27,097,656	-$728,999,439
Total	**-$1,613,409,611**	**-$265,746,915**	**$310,230,957**	**$839,926,130**	**-$728,999,439**
B/C ratio	**-**	**-**	**-**	**-**	**0.61**

Table A-13: Economic aggregation for Metro using income-dependent VOT.