

1.221J/11.527J/ESD.201J Transportation Systems

FALL 2004

ASSIGNMENT 3

Abating the Mobility and Air Quality Crisis in Mexico City

Date assigned: October 1, 2004

3A Date due: Lecture 10

Value: 10 points

3B Date due: Lecture 13

Value: 20 points

This assignment is a lot of work and accounts for 30% of your final grade. That is why we have given you a lot of time for it. Part 3A is due in a week and a half and Part 3B is due 3 weeks from today. This kind of assignment cannot be done well by pulling an all-nighter or two. There is thinking to be done that is best performed over time and writing to be done, before which you need to complete the quantitative analysis. Give yourself enough time to perform well.

On Tuesday, October 5, the second half of class will be a press conference. This is an opportunity for you to ask questions of the TA for clarification of the assignment. As such, please read the problem statement thoroughly so that you can come to class with questions prepared. At the very least, you should read the assignment so that you can understand responses to other students' questions. Be aware that broad, general questions such as "how do I do the assignment?" will not be accepted.

In addition, this assignment is spreadsheet-intensive. If you are well-versed with Excel or a similar spreadsheet software, you should not have much trouble putting the quantitative portion together. For those of you with less experience, there will be a tutorial on Wednesday, October 6 at 6:30 pm.

Instructions: Read this document in its entirety AT LEAST once, and then proceed.

1. Introduction

Welcome to the Mexico City Metropolitan Area, one of the world's largest and most historically significant cities. Centuries ago, Aztecs built an empire at Tenochtitlán that would later be conquered by a wave of Spanish explorers. Built subsequently atop the Aztec ruins, Mexico City today emerges as a city of layers: cultural layers, architectural layers, ethnic layers, geographic layers, and economic layers.

Modern Mexico City is plagued by a number of potentially disastrous natural and human crises: the Popocatepetl volcano, earthquakes, land subsidence, traffic congestion, and, perhaps most notably, air pollution. In fact, one of the most visible "layers" in Mexico City is the thermal inversion layer, a thick layer of airborne contaminants that sticks close to the ground most days as cold air at lower elevations becomes trapped by warmer air at higher elevations. Adding to the problem is a ring of mountains which nearly encircles the Valley of Mexico, leaving little opportunity for pollutants to escape. The high base elevation of Mexico City (about 7500 feet above MSL) further compounds the air quality problem due to lower concentrations of oxygen, which makes tuning of vehicle engines for optimal performance a challenging and costly task.

Although levels of some pollutants have declined in the last decade, Mexico City's air quality problem remains at a near-crisis stage. Exposure to pollutants is responsible for disease and chronic illness in children and the elderly; meanwhile severe pollution days and worker sick-days often inhibit the ability of Mexicans to work, thereby constraining economic growth.

Figure 1A is a topographic map of the Valley of Mexico, looking southeast. The two high peaks are the volcano Popocatepetl (right) and the peak of Iztaccihuatl (left). The "Valley of Mexico" describes the flat basin at center. The Mexico City Metropolitan Area (MCMA) covers much of the Valley of Mexico and is sometimes also called the "Zona Metropolitana del Valle de México" (ZMVM). In this assignment statement, "Mexico City" and MCMA are used interchangeably.

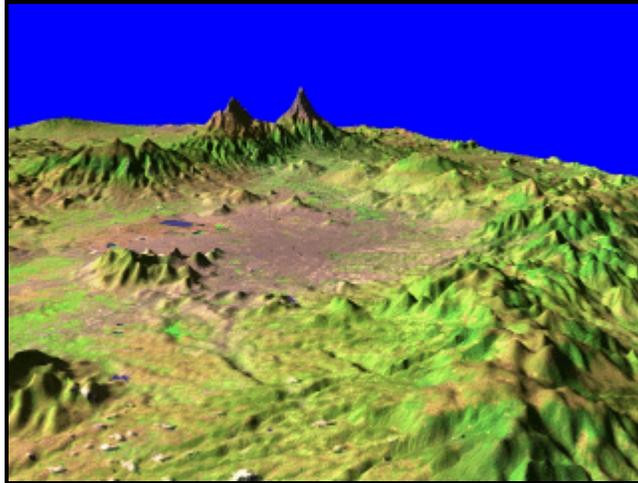


Figure 1A – Topo map courtesy of the MIT-Mexico City Program, created by Agustín García, NASA.

The transportation enterprise in Mexico City—a complex system composed of numerous modes, facilities, and institutions—contributes significant amounts of the pollutants responsible for air quality concerns: 20 percent of sulfur oxides (SO_x), 35 percent of particulate matter (PM_{10}), 40 percent of organic compounds (HC), 80 percent of nitrous oxides (NO_x), and nearly all of the region's carbon monoxide (CO). As population grows and economic development continues in the region, mobility of residents and freight becomes an increasingly important requirement. Unfortunately, many of Mexico City's streets, highways, and public transportation networks are heavily congested, which creates more air quality problems and reduces economic development.

At conflict in Mexico City are the goals of economic development and environmental improvements. Regional and national leaders are seeking strategies for mitigating environmental effects while facilitating expansion of the economy and of economic opportunities for a greater number of Mexicans. One of the most critical areas in which they hope to achieve this dual goal is through transportation policy.

Institutional issues add yet another aspect to the Mexico City situation. Because the urbanized region spreads across the Distrito Federal (herein referred to as the Federal District), large portions of the Estado de México (herein referred to as the State of Mexico), and a small portion of the State of Hidalgo, policies and regulations stem from numerous jurisdictions and regulating agencies. Coordinating the activities and plans of these agencies, the private sector, and related industries presents a particular challenge for Mexico City. Figure 1B below shows the political jurisdiction boundaries as well as the limits of the urbanized metropolitan area.

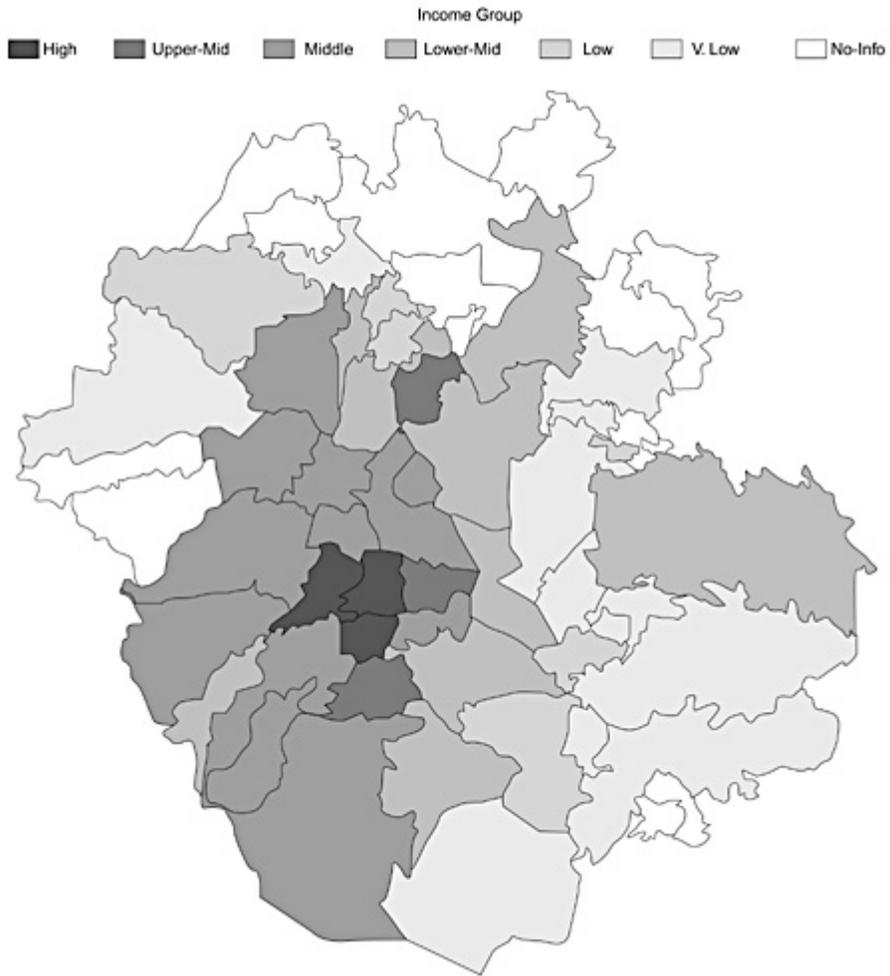


Figure 1B – Map of the political jurisdictions of the MCMA, by income level. (MIT OCW.)

2. Your assignment

You are to complete the tasks and deliver the various components of Assignment 3 using the tools, data, and other references at your disposal. External research is optional; it is **not** needed to complete successfully this assignment. The assignment asks you to use the given quantitative and qualitative evidence to help you select a combination of transportation policy recommendations from a set of options we have defined for you, and then analyze your recommendations from several different perspectives.

2.1 *The Situation*

Mobility and air quality problems have approached near-crisis proportions in the MCMA. Regional and national leaders are concerned about the problem. Last year, the national government commissioned a Technical Committee to research transportation options to help alleviate the problems. The Committee produced a detailed package of 14 options, including descriptions of the cost to implement each option along with its effects on congestion and the environment. These options, which will guide your work, are described in **Section 3**, summarized in **Section 4**, and quantified in **Appendix H**. Other detailed quantitative information (demographics, modal information, emission and congestion information, maps, and financial resources) appears in the other appendices.

In order to implement these options, the national government is considering a multi-billion dollar package of grants and loans to the Federal District and the State of Mexico. Unfortunately, there are not enough funds available to implement all of the options identified by the Technical Committee. Furthermore, political rivalry between the Federal District and the State of Mexico may preclude easy implementation of any package of options.

Please note that Mexico's national government is distinct from the government of the Federal District. In other words, the government of the Federal District is equivalent to the government of any other Mexican state. The Mayor of the Federal District and the Governor of the State of Mexico are politically equivalent; the two states simply use different terminology to describe the same job. Hierarchically, the national government is above the Federal District government and the State of Mexico government. Figure 2 depicts this hierarchy graphically.

In order to address financial and political complications arising from the package of options, the Minister of Finance (and official of the national government) recently

created a new committee, called the “Special Conference of the Mayor of the Federal District and the Governor of the State of Mexico,” in order to decide which options identified by the Technical Committee should be implemented to best improve air quality and mobility problems. Furthermore, in recognition of the political and financial difficulties it faces

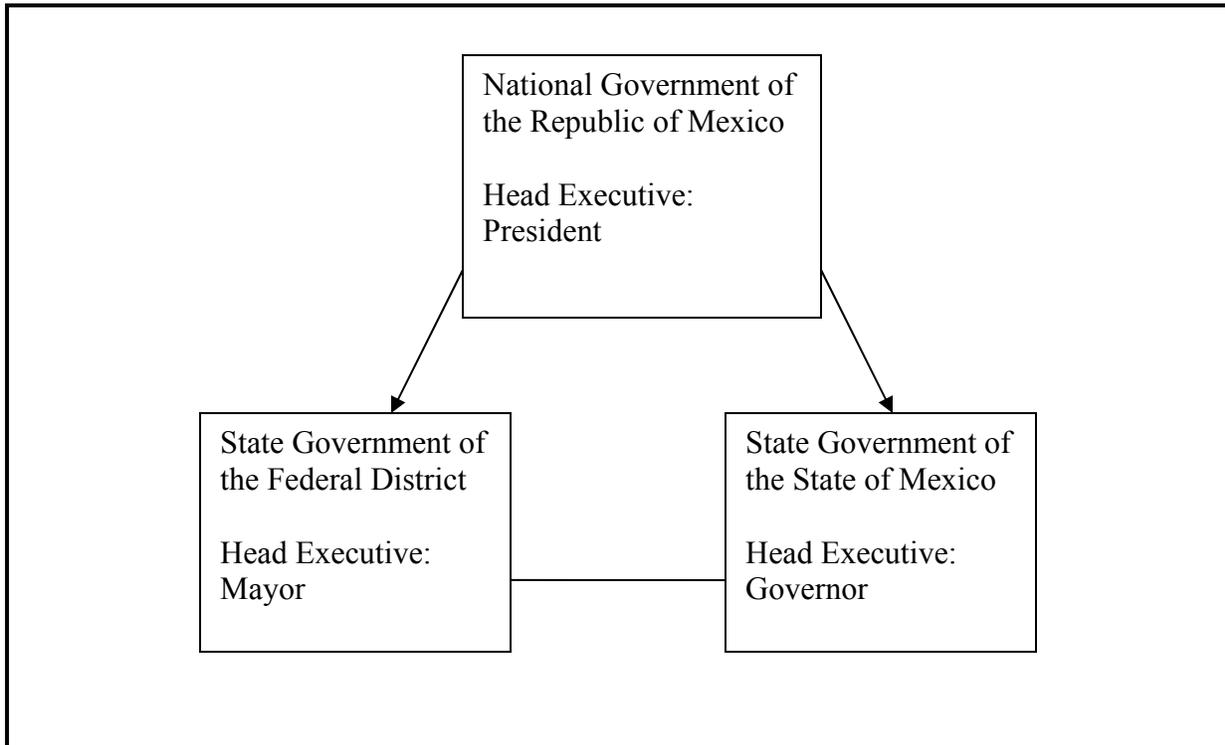


Figure 2A – Hierarchy of governmental authority

in attempting to oversee cooperation among the various regional leaders, the Special Conference has been given several operating guidelines:

- A. Total funds available to the region include \$5 billion in direct grants and a \$1 billion loan to be repaid interest-free in 10 annual installments of \$100 million each beginning in 2011 and ending in 2020. The grants and loan will be available to the Special Conference to administer on January 1, 2005. Do not consider interest or time value of money for this assignment.
- B. If annual pollution performance targets are met through 2016, then the region has the option to receive a one-time bonus grant of \$200 million in 2017. These performance targets are described in Appendix E.
- C. If either state (the Federal District or the State of Mexico) fails to agree to the proposal produced in Task 2, then the Special Conference will dissolve and each state will receive a modest allocation of \$400 million each for highway

construction. The remaining funds will be applied to transportation projects of national interest.

- D. The national government's Minister of Finance, Pedro Martinez, is the final arbiter of the Special Conference and reserves the authority to alter the allocation of funds however it sees fit.

In recent years, Senator Manuel Ramirez (a member of the legislative branch of the national government) has been building a coalition to support his efforts to bring transportation investments to his home state of Veracruz. Veracruz is a coastal state bordering the Gulf of Mexico whose capital city, also called Veracruz, lies approximately 200 miles east of Mexico City. Veracruz (also the title of a classic American film) is a major port for goods entering and leaving Mexico; in fact, it is the country's largest port for imports and exports. Senator Ramirez, recognizing the value of international competitiveness in the 21st century, hopes to invest in expanded and upgraded seaport facilities in Veracruz as well as in a corridor for rail and highway connecting Veracruz and the MCMA. The Senator's staff has estimated that Veracruz will need approximately \$0.5 billion for the seaport enhancements, \$3 billion for highway improvements, and \$2.5 billion for rail improvements. Ramirez fears that the congestion and air quality crisis in Mexico City may divert some of the funds that he and his staff have hoped would be used in Veracruz. The Senator has increasingly been seen in the National Palace, where the legislature meets, away from his office and observing, often participating in, regular meetings of the Special Conference staff.

2.2 Deliverables

Assignments 3A and 3B require the completion of 5 separate tasks. Each task is described below in detail. Background information to support your work is available in the subsequent sections of this report. Detailed quantitative information is available in the Appendices.

Assignment 3A consists of Task 1. Assignment 3B consists of Tasks 2, 3, 4, and 5. Throughout these tasks, you are asked to take on various roles. These roles include:

- (1) Chief policy advisor to the Special Conference of the Mayor of the Federal District and the Governor of the State of Mexico;
- (2) Chief of Staff of the Special Conference;
- (3) Senator Manuel Ramirez of Veracruz; and
- (4) Minister of Finance Pedro Martinez for the national government of Mexico.

2.2.1 Assignment 3A (DUE TUESDAY, OCTOBER 12 BY 5 PM)

TASK 1 (10 points): As chief policy advisor (role 1), produce a spreadsheet and a memo summarizing the “do-nothing” alternative for Mexico City transportation and air quality from 2005-2020 for the Office of Senator Manuel Ramirez, who represents the State of Veracruz in the legislative branch of the national government. Senator Ramirez believes that no more money should be spent within the MCMA and has proposed an alternative plan for a new seaport in Veracruz and rail/highway upgrades between the MCMA and Veracruz. Because of his presence and insistence at recent meetings, the Special Conference has agreed to perform the analysis and appointed you to fulfill the task. Ramirez has requested the “do-nothing” analysis in order to determine the impact on the MCMA of doing nothing. Of course, he hopes that the do-nothing alternative shows that the impact of doing nothing is not too severe for the MCMA, thereby strengthening his plan to secure more funds for his seaport and rail/highway project.

Given the background information in Section 3 and quantitative information in Appendices A through E, determine the following quantities for each year from 2005-2020: annual cost of congestion for freight, total annual cost of congestion, and total annual emissions of each of the five key pollutants (HC, CO, NO_x, PM₁₀, and SO_x). In addition, calculate the total cost of emissions during the analysis period assuming that you are charged a financial penalty for each year that you exceed the limits set for particular pollutants (Information explaining how to deal with financial penalties appears in Appendix E).

You will find that your solution must draw directly on all of the information contained in Appendices A through E except for population data. After building the spreadsheet model and determining the costs (costs in terms of dollars* and tonnes emitted), you should complete a memo summarizing the implications of doing nothing in the MCMA. The written memo should not exceed 1 page single-spaced.

2.2.2 Assignment 3B (DUE FRIDAY, OCTOBER 22 BY 5 PM)

TASK 2 (12 points). Again, as chief policy advisor (role 1), produce a comprehensive report for the Special Conference’s Chief of Staff describing the results of your analysis and outlining your recommendations for 2005-2020. Your report should address all the issues described in this problem statement and present a set of recommendations for transportation investment, justified both quantitatively and qualitatively. This “set of recommendations” consists of a set of policy options you will select from those already

* All values given in this assignment are in 2005 US dollars. Do not worry about currency conversion or inflation.

defined by the Technical Committee and discussed at length in Section 3 and Appendix H. You should also discuss policy options available to you from Appendix H that you decide not to pursue and explain why you choose not to include them.

Your report should document all improvements, investments, and other actions taken among the 14 policy options. Remember that as the chief policy advisor for the Special Conference, your goal is to produce a set of policies that will best address the problems of congestion and air quality within the funding guidelines prescribed in Section 2.1 and Appendix G. Use whatever metrics you would like in order to decide what is “best” (e.g., cost to the government, cost to the residents of the MCMA, emissions reductions, equity, etc.). Just be sure to justify your decisions using both the quantitative data provided here and qualitative considerations.

Lengths of the reports will vary; however, we judge that you will need about 10-15 pages single-spaced (including tables and charts). Your document will constitute the officially-endorsed policy of the Special Conference and is a public document. Public documents can be accessed by the general public; this includes your supporters and detractors.

TASK 3 (2 points). As Chief of Staff (role 2), read the report produced in Task 2 and write a memo to the National Minister of Finance Pedro Martínez summarizing the recommendations. Do not exceed 2 pages single-spaced. This is a public document.

TASK 4 (5 points). As Senator Ramirez (role 3), review the information from tasks 1, 2, and 3. You have promised your constituents to work for funding of a new seaport in Veracruz and a rail/highway link between the MCMA and the port of Veracruz. Given obligations to your constituents as well as your knowledge of the two (potentially very divergent) future scenarios for the MCMA presented in tasks 1 and 2, write a memo to the National Minister of Finance summarizing your position.

You represent the interests of Veracruz, but you’re also pragmatic and realize that it is unlikely that you will receive all \$6 billion. You also understand the importance of the MCMA to the national economy of Mexico. Nevertheless, you will seek reasonable ways to transfer funds from the MCMA to Veracruz. Specifically, you are looking for flaws in the analysis, flaws in the assumptions, and opportunities among the revenue sources.

In addition, you have on your staff Dolores del Río, a graduate of the MST program at MIT. Del Río “knows her stuff” and, in fact, did an analysis similar to Task 2 when she was in graduate school at MIT. Because of del Río, you are well-informed and your

memo should be insightful, identifying particular flaws and opportunities for the Veracruz group.

In your memo, you may demand funding for your seaport and rail/highway link, you may concede that the funds will be better spent in the MCMA, or you may ask for some compromise. There is no correct answer, but you should use this opportunity to point out any flaws in the assumptions underlying Task 2 (i.e., the Appendices of this document) as well as any flaws you see in the decisions made by the chief policy advisor in Task 2 and in the other policy alternatives that would make funds available to your pet projects. Do not exceed 3 pages single-spaced. This is a public document.

TASK 5 (1 point). Minister of Finance Pedro Martínez probably did not read the report you produced in Task 2, but did read the summary from Task 3 and the Senator's memo from task 4. Now, assuming the role Minister of Finance (role 4), and based on your reading of Tasks 3 and 4, write a memo to the Mayor of the Federal District, the Governor of the State of Mexico, and Senator Ramirez summarizing your allocation decision and stating the reasons for your decision. Do not exceed 1 page single-spaced. This is a confidential document.

2.2.3 Guidelines & Disclaimers

This assignment has both quantitative and qualitative aspects. Your work will be assessed on how well you have thought through the issues, defended your assumptions, incorporated the available information, and presented your case. This assignment is a gauge of your quantitative skills as well as your abilities to present your arguments *professionally*. Defend your arguments, explain your quantitative approach, and present yourself in a manner befitting a senior bureaucrat, a Senator, and a national leader.

Many of the data for this assignment are real or based largely on reality. Others are estimates. Some are simply made up for this assignment and may not be realistic. Virtually all of the policy options have been discussed in some form in the MCMA. This has been done in order to streamline your quantitative work. The Special Conference is fictional, as are the \$5 billion grant and \$1 billion interest-free loan. If you have a special interest in Mexico City and would like to know more about the basis for the quantitative and/or qualitative aspects of this problem in Mexico, feel free to contact the Teaching Assistant.

2.2.4 How to proceed

First, proceed by reading Sections 3 and 4 and the Appendices in detail at least once. Next, complete Assignment 3A in its entirety. The spreadsheet you create for 3A will serve as the basis for your exploration of various policy options in Assignment 3B. We will provide the solution to 3A--after everyone submits it, naturally--so that you can confirm that your quantitative assessment is accurate before you begin to explore options for 3B. If you choose to do additional background research, it is highly recommended that you do so only upon completion of 3B. If you have any additional questions or need clarification on any of the tasks, data, or strategies for completing this assignment, please do not hesitate to contact either Professor Sussman or the TA.

Two final pieces of advice: (1) Start working now! Assignment 3 is a time-consuming task. You will not be able to complete these tasks the day before the assignment is due. We have tried to encourage you to start early by requiring submission of 3A, so do not allow yourself to get behind. (2) Have fun! While this assignment can be quantitatively rigorous and requires consideration of numerous complex, inter-related issues, it should be a fun exercise.

3. The issues

This section describes issues associated with passenger transportation modes and freight transportation modes in the MCMA. Descriptions of policy options available within each mode are described here and numbered (1) through (14), but more thorough descriptions of the options and essential quantitative information appear in Appendix H.

3.1 *Passenger modal policy issues*

3.1.1 *Taxi*

The large Mexico City taxi vehicle fleet (110,000) contributes to both air quality and congestion problems. Due to concerns from the taxi driver unions, the primary taxi policy options are: (1) subsidize purchase of new taxis equipped with more advanced emissions technology and (2) law enforcement effort to round up illegal, unlicensed, “pirate” taxis operating throughout the MCMA.

3.1.2 *Informal Transportation (Colectivo)*

Nearly half of all trips in Mexico City are by informal transportation providers called colectivos. Informal providers consist of a fleet of nearly 40,000 largely individually-owned and operated “colectivos,” ranging in size from 8-passenger vans to 25-seat minibuses, though most are 25-seat minibuses. Colectivos operate without formal route structures, and make frequent, unscheduled stops along major thoroughfares to pick up and drop off customers, thereby contributing significantly to the congestion and air quality problems. While colectivos operate throughout the MCMA, one of their most important constituencies is the State of Mexico, where Metro subway service does not exist. Colectivos offer mobility to the millions living in the State of Mexico who have no access to formal transportation options.

There are currently forty-six Modal Transfer Centers (Centros de Transferencia Modal, or CETRAMs) in the MCMA, mostly located in the Federal District; however, these facilities are largely overcrowded, inefficient, and poorly-operated. CETRAMs in the Federal District allow for passengers to transfer between Metro and colectivo; CETRAMs in the State of Mexico allow for passengers to transfer between colectivos. Upgrading existing facilities would improve capacity and reduce delays. Meanwhile, new facilities would be larger, constructed in the State of Mexico, and allow for greater volumes of colectivo-colectivo transfers.

Policy options to improve the performance of colectivos include the following: (3) better integrating colectivos with formal public transportation as an intermodal “feeder” through construction of new intermodal connector facilities and improvements to existing intermodal connector facilities (4) subsidies for purchase of new colectivos equipped with more advanced emissions technology.

3.1.3 *Private auto*

Roughly one quarter of travel in the MCMA is by private auto. In spite of congestion and the relatively high cost of owning a personal vehicle, Mexicans are increasingly taking to the roads in personal cars. In fact, as incomes rise, car ownership increases at an even higher rate.

Major area roadways include the Periférico (a peripheral “ring road” that, more or less, encircles a large part of the MCMA) and a network of interior highways. A short segment of a second ring road (“Anillo Exterior,” or Outer Ring—see blue lines in Map 1 of Appendix I) has already been completed in the far western part of the region.

Policy options to address this mode of travel include: (5) imposing a vehicle toll on several area roadways, including the network of interior highways and/or the Periférico (6) implementation of Intelligent Transportation Systems (ITS) components including variable message signs, closed-circuit video cameras for hazard and incident identification, traffic signal synchronization, and investment for exploration of further operations strategies and (7) construction of the remaining segments of the Outer Ring highway.

3.1.4 *The Metro*

Mexico City’s subway system (Metro) covers a large portion of the metropolitan area within the Federal District. With 11 lines, 167 stations, and over 200 kilometers of track, it serves about 1.4 billion riders annually, making it the 3rd largest system in the world in terms of ridership. Leaders expect that increasing ridership on the Metro will reduce the number of vehicles on the road. Figure 3 below shows a map of the Metro system.

Unfortunately, the cost of expansion of the system is high. Furthermore, the Metro system currently does not reach the MCMA population living in the State of Mexico, which accounts for roughly half of the metropolitan population. Instead, subway lines extend only to the periphery of the Federal District, leaving millions in the State of Mexico un-served or underserved.

While there are many ideas for Metro expansion, for political reasons, the single policy option we consider for the Metro is (8) reduce the fare.

3.1.5 Diesel buses

The formal, publicly-operated bus system in Mexico City has seen steady declines in ridership over the past decade as different operations strategies have continually failed to attract riders and as competition from the colectivos has offered a more appealing and convenient transportation option to riders. On the other hand, proposed bus rapid transit (BRT) lanes would accompany general travel lanes along many of the region's major thoroughfares, including the Avenida Insurgentes. If constructed, BRT would replace the current publicly-operated bus system and compete with all other modes for travelers. The policy option for the bus is: (9) reduce currently-planned fare increases and construct infrastructure for a bus rapid transit network.

3.2 Freight modal policy issues

This section describes road- and rail-based freight transportation in the MCMA. Currently, there are an estimated 400,000 road-based freight vehicles, many of which contribute significant amounts of emissions and which add to the region's congestion. In 1995, road-based freight moved 627 million tonnes of goods, while railroads carried just 8 million tonnes.

The four primary vehicle types are:

1. Light-duty gasoline truck
2. Heavy-duty gasoline truck
3. Heavy-duty diesel truck
4. Natural gas truck

A large amount of the emissions in the MCMA comes from heavy-duty freight vehicles traveling within the region and to destinations outside of the region. To alleviate the impacts of these types of trips, freight transfer facilities at the periphery of the city have the potential to reduce the amount of freight travel by transferring loads to smaller trucks for inner city deliveries and routing through traffic away from the city center.

The policy options for the freight fleet are somewhat limited by a number of factors. First, the freight fleet is largely owned and operated by private companies. Much of the freight activity in the MCMA is for local deliveries by local companies with their own vehicles. Regulating local deliveries can be a difficult task. Since the average age of the fleet is 16 years, one especially promising policy to pursue is renewal of the fleet; unfortunately, the financial resources available to the operators of these trucks in Mexico are very limited.

There are, nonetheless, several available options: (10) subsidize purchase of natural gas trucks (11) invest in a publicly-owned and operated logistics company to research and implement technologies and strategies for optimization of freight fleet utilization (12) build freight transfer facilities at the periphery and (13) invest in the railroad infrastructure to increase railroad utilization for freight.

3.3 Economic investment

A fourteenth option is to invest \$1.5 billion in the construction of job-intensive manufacturing plants in the State of Mexico. Industries include textile, petroleum, and auto manufacturing. The benefit in terms of transportation is to bring jobs for poorer classes closer to their homes in the periphery of the region, thus reducing travel needs.

3.4 Constraints

Environmental and transportation experts believe the above-outlined policy options will improve the performance of the transportation system while mitigating some environmental impacts. Of course, some are more cost-effective than others. The fiscal and political realities of Mexico City impose a few constraints on the ability of leaders to enact all of these measures. These complications are outlined below. Some of this information is essential to your work, and some is merely informative.

3.4.1 Colectivo drivers

The colectivo drivers' association is opposed to any form of regulation by the government and has threatened to strike if they perceive that the costs borne unto them by any plan exceed a reasonable amount. Such a strike could have disastrous effects for the millions of riders they serve daily. The government, while bothered by the operating habits of colectivos, nonetheless recognizes the importance of colectivos as providers of mobility. The demands of the colectivo drivers are as follows: they will strike if any regulation requires purchase of new colectivos. The only acceptable alternative is to offer subsidies for purchase of any new vehicles.

3.4.2 Taxi drivers

The taxi drivers' association, much like that of the colectivo drivers, is suspicious of government attempts to regulate their fleet. In order to keep costs down, the taxis have also asked for a 100% subsidy under any fleet renewal plan.

3.4.3 The airport and rail corridor lobby

Senator Manuel Ramirez represents the State of Veracruz in the legislative branch of the national government and has promised his constituents he would seek funds for construction of a new airport and high speed rail line connecting the MCMA with the port of Veracruz. Senator Ramirez opposes the Special Conference's mandate of pouring billions of dollars into Mexico City infrastructure and transportation policy because he feels that the money will be poorly-spent. Furthermore, he is championing the notion of global and national connectivity for Mexico as a whole rather than focusing disproportionate investment in one region. To fund his vision, the Senator is seeking \$6 billion for construction of a major new international airport near Veracruz and a high speed passenger rail and freight rail corridor linking Mexico City with the port of Veracruz.

3.4.4 Federal District-State of Mexico equity

Within the MCMA, the Federal District historically has been the beneficiary of greater subsidies than the State of Mexico. The Governor and other leaders of the State of Mexico have promised their constituents that the Special Conference will recommend a more equitable distribution of funds and programs across the region than in previous decades. If the proposed program of improvements has even the appearance of favoritism toward the Federal District, the Governor of the State of Mexico has promised to abandon the proceedings altogether.

The stipulations put forth by the federal government in arranging the Special Conference state that agreement among the Federal District and State of Mexico be reached; abandonment by either party would result in a modest allocation of \$400 million to each jurisdiction in 2005, with the balance of the grant in such a case being immediately awarded to Senator Ramirez's projects. The conditions for agreement among the two states is that neither may receive less than 40% of direct benefits from the grant and loan funding. "Benefits" is a term roughly describing the economic gains to be realized through construction and operation of a project. A breakdown of benefits between the Federal District and the State of Mexico is mentioned at the end of each option's description in Appendix H.

4. Summary of Policy Options

In the previous section, policy options were presented within a description of the many existing transportation enterprise of the MCMA. These options are listed below:

1. Subsidize renewal of the taxi fleet.
2. Roundup illegal "pirate" taxis.
3. Construct new colectivo intermodal facilities and upgrade existing facilities.
4. Subsidize renewal of the colectivo fleet.
5. Implement tolls on several area roadways.
6. Expand Intelligent Transportation Systems (ITS) components.
7. Finish construction of the Outer Ring highway.
8. Reduce the fare for the Metro.
9. Convert from diesel on-street buses to Bus Rapid Transit (BRT).
10. Subsidize purchase of natural gas trucks for the freight sector.
11. Invest in a public freight logistics company.
12. Build freight transfer facilities at the periphery of the MCMA.
13. Improve the railroads throughout the MCMA.
14. Build government-sponsored manufacturing plants in the State of Mexico.

Appendix A: Demographic data

Your period of analysis is 2005-2020. According to the Mexican Census, the 2005 population of the MCMA is 17.5 million persons, split equally between the Federal District and the State of Mexico. Assume an annual growth rate of 1.5% for the MCMA through 2020.

Transportation data analysts at the Secretaría de Transporte y Vialidad (Transportation and Roads Secretariat, or SETRAVI) predict that in the MCMA in 2005, there will be 87,797,725,000 person-kilometers traveled (PKT). This number is expected grow by an annual rate of 2.6% through 2020.

Appendix B: Modal data

Section 1. Passenger modal characteristics

The following table (B-1) shows the average costs, in-vehicle travel times, and out-of-vehicle travel times for each of the five passenger modes in the MCMA.

Table B-1: Average cost, IVTT, and OVTT for a trip by passenger mode in 2005

Mode	Cost (US dollars)	In-vehicle travel time (minutes)	Out-of-vehicle travel time (minutes)
Taxi	5	23	4
Colectivo	0.4	41	18
Private auto	0.33	43	5
Bus	0.5	45	25
Metro	0.2	44	19

The annual rate of growth (compounded annually) for some of these variables is presented in Table B-2:

Table B-2: Growth of cost, IVTT, and OVTT from 2005-2020

Mode	Annual cost growth (%)	Annual IVTT growth (%)	Annual OVTT growth (%)
Taxi	1.0	1.0	0.0
Colectivo	1.0	1.0	0.0
Private auto	1.0	1.0	0.0
Bus	n/a*	1.0	1.0
Metro	n/a*	0.0	0.0

*The future costs of bus and Metro are based on a schedule of cost increases. See table B-3:

Table B-3: Future cost schedules for the bus and Metro

Year	Cost of bus (US dollars)	Cost of Metro (US dollars)
2005	0.50	0.20
2006	0.75	0.40
2007	0.75	0.40
2008	0.75	0.40

2009	0.75	0.40
2010	0.75	0.40
2011	1.00	0.60
2012	1.00	0.60
2013	1.00	0.60
2014	1.00	0.60
2015	1.00	0.60
2016	1.50	0.75
2017	1.50	0.75
2018	1.75	0.75
2019	1.75	0.75
2020	1.75	0.75

Please note that the costs presented for each mode in the above tables constitute the “perceived out-of-pocket costs” to users of the transportation network. These perceptions help to determine their choice of mode. In order to estimate mode choice for trips in the MCMA, use a logit model as described below.

The **percentage** (mode share) of person vehicle-kilometers allocated to mode i is determined by the following equation:

$$\frac{e^{V_i}}{\sum_j e^{V_j}}, \text{ where } V_i \text{ is the utility of mode } i, \text{ and } V_j \text{ is the utility of mode } j.$$

For example, the mode share of taxi would be given by the following expression:

$$\frac{e^{V_{\text{taxi}}}}{e^{V_{\text{taxi}}} + e^{V_{\text{colectivo}}} + e^{V_{\text{auto}}} + e^{V_{\text{bus}}} + e^{V_{\text{metro}}}}$$

The utility function for each of the modes is given below, where C is average “perceived, out-of-pocket cost,” I is average in-vehicle travel time, and O is average out-of-vehicle travel time.

$$V_{taxi} = 4.86 - 0.595C_{taxi} - 0.05106I_{taxi} - 0.2142O_{taxi}$$

$$V_{colectivo} = 9.95 - 0.595C_{colectivo} - 0.06663I_{colectivo} - 0.3035O_{colectivo}$$

$$V_{auto} = 3.40 - 0.595C_{auto} - 0.0461I_{auto} - 0.07624O_{auto}$$

$$V_{bus} = -0.595C_{bus} - 0.001989I_{bus} + 0.01131O_{bus}$$

$$V_{metro} = 0.495 - 0.595C_{metro}$$

The average vehicle occupancy of the various modes is listed in Table B-4 below:

Table B-4: Average vehicle occupancy

Taxi	1.09 persons per vehicle
Colectivo	17.44 persons per vehicle
Auto	1.80 persons per vehicle
Bus	9.40 persons per vehicle
Metro	62.00 persons per vehicle

To convert from person-kilometers traveled (PKT) to vehicle-kilometers traveled (VKT), simply divide the number of PKT by the average persons per vehicle. For instance, given 100 taxi PKT, the number of VKT is: (100PKT)/1.09 = 91.7 VKT.

Section 2. Freight modal characteristics

SETRAVI analysts determined that the number of freight VKT in the MCMA in 2005 will be 8,550,000,000. The annual growth rate of freight VKT through 2020 is 1% (compounded annually). There are five modes of freight transportation in the MCMA: light duty gas trucks (LDG), heavy duty gas trucks (HDG), heavy duty diesel trucks (HDD), natural gas trucks (NG), and railroad (RR). Table B-5 lists each of these modes and their share of freight VKT in 2005.

Table B-5: Freight mode shares

Mode	Share (% of VKT)
LDG	25
HDG	20
HDD	49
NG	1
RR	5

The mode share of natural gas is forecasted to grow by 5% annually through 2020. Please use caution. This means 5% growth of the mode share so, for example, in 2006, the mode share will see a 5% increase over the mode share of 2005: $0.01 \times 1.05 = 0.0105 = 1.05\%$. In 2007, the mode share will increase another 5%: $0.0105 \times 1.05 = 0.011025 = 1.1\%$, etc.

The mode share of rail is forecasted to decline by 5% each year, compounded annually, through 2015 and by 2% each year from 2016-2020. Please note that for both this and the NG computation, year i 's increase or decline is compounded annually, meaning that values are computed using the mode share value from year $i-1$ as the base year (**not** the starting year, 2005). A carefully-designed spreadsheet does many of these calculations automatically.

The impact of changes in mode share of railroad and natural gas trucks on the other three modes is equal. For example, if natural gas and railroad mode shares combined increase by 3% in a given year, then the mode shares of LDG, HDG, and HDD each decline by 1%.

Appendix C: Emissions Data

The amount of emissions of five criteria pollutants will be central to your analysis. Emissions are determined by a simple operation: multiply the annual VKT of a particular mode by its emission factor for a particular year. The emission factors for the year 2005 for the 10 modes discussed in Appendix B (5 for passenger, 5 for freight) are presented in Table C-1.

Table C-1: Emission factors. Note that 1 tonne = 10⁶ grams. Present your total emissions values for parts 3A and 3B in tonnes.

Mode	HC	CO	NO _x	PM ₁₀	SO _x
	Grams/VKT				
Taxi	2.89	33.35	1.37	0.029	0.09605
Colectivo	4.75	11.75	14.41	1.500	0.3157
Auto	3.15	42.26	0.96	0.101	0.2341
Bus	7.57	82.63	2.61	0.029	0.11497
Metro	0	0	0	0	0
LDG	0.2730	3.28	0.392	0.049	0.0275
HDG	0.864	9.88	1.766	0.746	0.075
HDD	3.001	34.71	5.051	1.498	0.027
NG	0.027	0.35	0.045	0	0
RR	0.42	1.6	0.15	0.08	0.014

As technology improves, emissions from vehicles will decrease. Consequently, emission factors will decrease over time. Table C-2 provides a schedule of declining emission factors over time. Please note that the percentage decrease is compounded annually. Again, a carefully-designed spreadsheet can make many of these computations automatic.

Table C-2: Annual percentage decrease in value of emission factors from previous year for all pollutants by passenger mode

Year	Taxi, %	Colectivo, %	Auto, %	Bus, %
2005	0	0	0	0
2006	0	0	0	2
2007	0	0	0	2
2008	0	0	0	2
2009	0	0	0	2
2010	0	0	0	2
2011	5	2	1	3

2012	5	2	1	3
2013	5	2	1	3
2014	5	2	1	3
2015	5	2	1	3
2016	2	1	2	1
2017	2	1	2	1
2018	2	1	2	1
2019	2	1	2	1
2020	2	1	2	1

For Metro, LDG, HDG, HDD, NG, and RR, emission factors are expected to remain constant through 2020.

Appendix D: Cost of congestion

As VKTs for both freight and passenger modes increase, the roadways in the MCMA will become constrained beyond current levels, which already are experiencing demands that far exceed capacity for much of the day most days of the year.

Compute total VKT for the MCMA by adding together the modal VKT of all road-based modes for both passenger and freight (note that this excludes the Metro and Railroad modes). **Do not** worry about conversion factors for buses or trucks. In other words, “a vehicle is a vehicle is a vehicle” for our purposes.

Total capacity of the roadway network in the MCMA in 2005 is 21 billion VKT. This capacity is expected to grow at an annual rate of 2% through 2020 compounded annually. For every VKT that exceeds the capacity in a given year, there is a contribution to congestion. To determine this contribution, consider the following:

- If VKT demand exceeds capacity by less than 10%, there is no congestion.
- If VKT demand exceeds capacity by between 10-20%, then all VKT suffer a delay of 0.25 minutes per VKT.
- If VKT demand exceeds capacity by between 20-30%, then all VKT suffer a delay of 0.50 minutes per VKT.
- If VKT demand exceeds capacity by between 30-40%, then all VKT suffer a delay of 1.0 minutes per VKT.
- If VKT demand exceeds capacity by between 40-50%, then all VKT suffer a delay of 2.0 minutes per VKT.
- If VKT demand exceeds capacity by 50% or more, then all VKT suffer a delay of 4.0 minutes per VKT.

For example, if capacity is 25 billion VKT and demand is 34 billion VKT, then demand exceeds capacity by: $(34-25)/25 = 36\%$. In this case, the 34 billion VKT suffer a delay of 1.0 minutes per VKT, or 34 billion minutes.

One hour of delay costs passengers \$1.20 and freight \$11.20.

You will need to compute the cost of delay to passengers, to freight, and overall.

Appendix E: Cost of emissions and fines

Limits on total emission of pollutants for the years 2005-2020 are presented in Table E-1:

Table E-1: Emissions limits in tonnes per year and fine for non-compliance in US dollars

	HC	CO	NO _x	PM ₁₀	SO _x
2005-2008	95,000	1,000,000	90,000	13,500	5,000
2009-2012	100,000	1,000,000	90,000	13,500	5,000
2013-2016	100,000	1,000,000	85,000	13,000	4,500
2017-2020	100,000	950,000	85,000	13,000	4,500
Fine	\$10 million	\$20 million	\$10 million	\$5 million	\$5 million

If, in any year, emissions for a pollutant are exceeded by any amount, the national government will assess a flat fine to be paid by the Special Conference. The amounts of the fines do not increase over time, but they can be assessed multiple times. For example, if the MCMA emits more than 1 million tonnes of CO in 2005 and again in 2006, the Special Conference will be fined a total of \$40 million, \$20 million in each year.

Appendix F: Maps of the MCMA

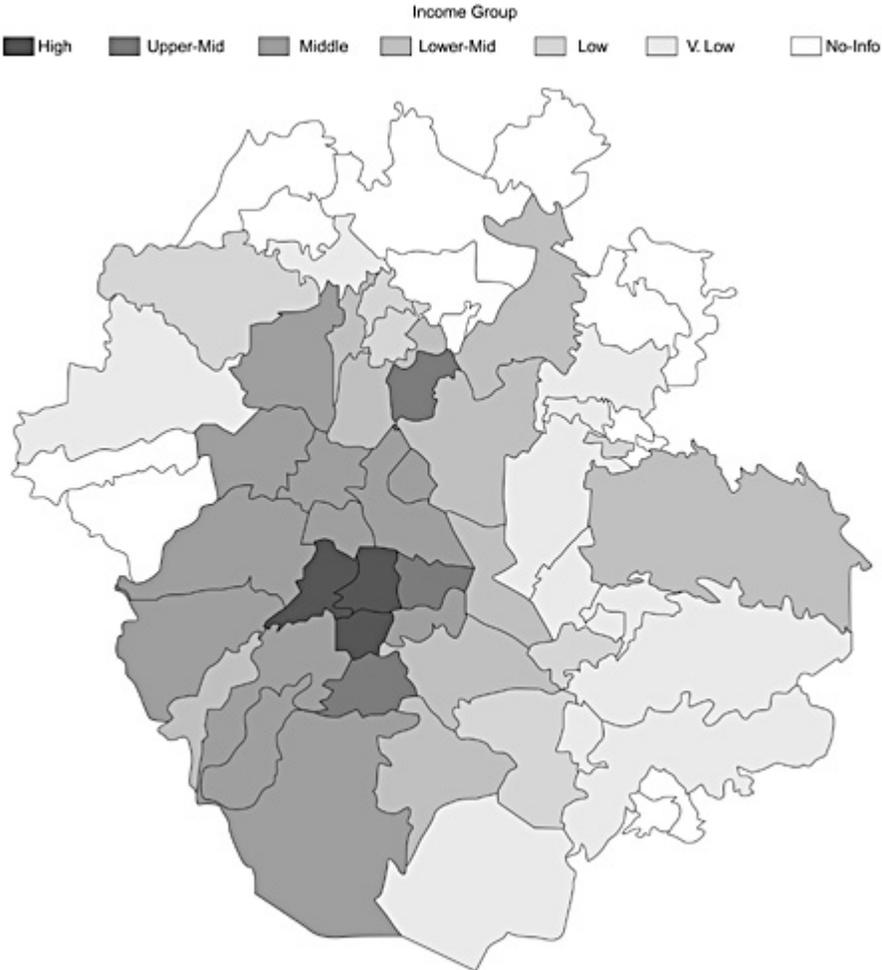


Figure 12 – Map of the political jurisdictions of the MCMA, by income level. (MIT OCW.)

See also:
Perry-Castaneda Mexico Maps

Appendix G: Finances

The national government is prepared to offer a grant of \$5 billion and a no-interest \$1 billion loan to the MCMA. The purpose of the Special Conference is to determine a program of transportation improvements and policies that will utilize these funds in an effective manner. As policy advisor, you will determine the program of improvements and policies (Task 2, Assignment 3B), but you must do so within the funding constraints and opportunities described here.

The grant and loan monies will be available in full on January 1, 2005. **These funds do not bear interest.** In other words, do not take into account the time value of money for any of your computations for this assignment. The loan must be repaid in 10 installments of \$100 million, paid on January 1 of each year beginning in 2011 and running through 2020. You are not required to spend the entire amount, and you may carry a negative balance from year to year, so long as you do not have a debt remaining in 2020. However, no negative balance from year to year may exceed \$500 million.

Fines for non-compliance with emissions standards are due at the end of the year in which the fine occurred. In addition, the Special Conference must contribute a fine equal to 10% of the total cost of congestion payable at the end of each year regardless of compliance or non-compliance with emissions standards.

If you have paid no emission fines through the end of 2016 (i.e., if you are in compliance for all pollutants through 2016), then the Special Conference will receive a one-time grant at the beginning of 2017 in the amount of \$200 million.

The Special Conference must fund its activities from the \$5 billion grant, \$1 billion loan, and other revenue sources. The annual cost of the Special Conference is \$200,000. Although modest in comparison to the entire budget, do not neglect this amount; it represents your salary!

Do not concern yourself with “time value of money” for any part of this assignment, assume zero inflation, and assume all values are in US dollars (i.e., there is no need to convert to other currencies).

Appendix H: Policy options, costs and effects

- Option 0: Do-nothing

For Assignment 3A, you will evaluate the do-nothing alternative as described in Section 2. For Assignment 3B, you will examine options 1 through 14 and attempt to formulate a better alternative than the do-nothing alternative.

- Option 1: Subsidize renewal of the taxi fleet.

Each new taxi will cost \$10,000. There are currently about 110,000 licensed taxis (plus about another 20,000 illegal taxis) on the roads in the MCMA. You may purchase as many as 40,000 new taxis in bundles of 5,000. New vehicles are available for purchase beginning in 2006. They are available for purchase through 2010. Each bundle of 5,000 new taxis replaces 5,000 old licensed taxis. As a result, the overall taxi fleet becomes newer. Since new taxis have better emissions technology, the emission factors for the taxi mode decreases by 1% for each bundle purchased in the year in which the purchase occurs **and in all subsequent years**. For example, without Option 1, the emission factors for taxis remains constant from 2006-2010. If you purchase a bundle of 5,000 taxis in 2006, the emission factors will be reduced by 1% in 2006, 1% in 2007, etc. In 2011, without Option 1, taxis are expected to see a 5% reduction. Your decision to purchase a bundle of taxis in any year prior to 2011 means that the annual reduction from 2011-2015 will be 6%. For 2016-2020 the reduction rate will be 3%. This policy will not affect traveler costs of using taxis, travel times, or congestion.

You may decide the ratio at which new taxis replace existing Federal District taxis or State of Mexico taxis (e.g., you can exclusively replace State of Mexico taxis or Federal District taxis, or some percentage of both). A taxi that replaces a Federal District taxi benefits the Federal District 100%. Likewise, a taxi that replaces a State of Mexico taxi benefits the State of Mexico 100%.

- Option 2: Remove illegal taxis from the road.

At an annual enforcement cost of \$30 million, you may direct the police of both the Federal District and the State of Mexico to identify and remove illegal, unlicensed “pirate” taxis from area roadways. If you choose to pursue this policy, you must begin funding the program in 2005. The effect of removing taxis is to reduce the number of available taxis, thereby decreasing competition and increasing prices. As a result, the average perceived out-of-pocket cost of a taxi trip will increase by 10% in 2006 only.

If the program of enforcement is discontinued, the average cost of a taxi trip will return to \$5.00 in the following year. Once discontinued, you may not re-start the program through 2020. For instance, if you choose this policy, taxi cost rises by 10% above and beyond the annual increase in 2006. Taxi costs increase at the annual rate (1%) each subsequent year until you discontinue the program. If your last year of funding for the program is 2010, then the cost of taxi will return to \$5.00 in 2012. From there, the annual compounded growth of 1% continues.

The benefits of this policy are equal for both states.

- Option 3: Construct and upgrade Metro-colectivo intermodal facilities

You can construct as many as 10 new CETRAMs, all of which will cost \$30 million and be located in the State of Mexico. You may also refurbish and expand up to 20 existing CETRAMs in the Federal District at a cost of \$10 million each. Funds must be paid in 2005. Facilities (new or refurbished) will open at the beginning of 2008. Because CETRAMs allow for easier transfer among modes, they also allow travelers to reduce the length of journey. As a result, each new State of Mexico facility results in a 0.6% reduction in total PKT for the year 2008 only. Each refurbished Federal District facility results in a 0.2% reduction in total PKT for the year 2008 only.

Assume that, although overall PKTs decreases, the proportion of ridership for all modes remains the same; that is, there is no change in the mode share for this option.

New facilities benefit the State of Mexico, while refurbishing and expanding old facilities benefit the Federal District.

- Option 4: Subsidize renewal of the colectivo fleet.

Each new colectivo will cost \$75,000. There are currently approximately 37,500 colectivos on the roads in the MCMA. You may purchase as many as 10,000 colectivos in bundles of 1000. Purchases must be made before 2010. Each bundle of 1000 colectivos replaces 1000 old colectivos. As a result, the emission factors for the colectivo mode decreases by 1% for each bundle purchased in the year in which the purchase occurs **and in all subsequent years** (see discussion in option 1). Seventy-five percent of any subsidies will benefit the State of Mexico.

- **Required Option 5: Tolls**

The Finance Minister, in order to minimize the national government's burden in investing in MCMA transportation, has stipulated that the Special Conference begin tolling existing roadways to raise more revenues. There are two options, and you can elect to exercise one or both of these options, but you **must** select at least one:

- 1) Place a toll on the Periférico every 10 km.
- 2) Place a toll on interior expressways every 50 km.

For option 1, the number of VKT_i on the Periférico in year *i* is a function of the toll amount and of the MCMA population as follows:

$$VK T_{i\Box} = (100,000 \times T_{i\Box} + 10,000,000 \times T_{i\Box}^2 + 1.5 \times P_{i\Box}) \times 25, \text{ where}$$

T_i = toll amount per 10 km in year *i*, and
P_i = population in year *i*.

For year 2005, the toll is fixed at zero. For years 2006-2020, you can set the toll in increments of \$0.05. You may set the toll using whatever strategy you prefer: to maximize revenue, to minimize congestion, to minimize emission, etc.

For the interior expressways of the region, VKT_i in year *i* is a function of the toll amount and of the MCMA population (similar to the toll function for the Outer Ring).

$$VK T_{i\Box} = (10,000,000 \times S_{i\Box} + 600,000,000 \times S_{i\Box}^8 + 2 \times P_{i\Box}) \times 100, \text{ where}$$

S_i = toll amount per 50 km in year *i*

Again, for the interior expressways, select a toll in increments of \$0.05. The toll may change from year-to-year.

Note that whatever toll amount you set will affect the average "perceived, out-of-pocket" cost used for the auto mode in the logit mode choice model. For the Periférico, 0.1% of the toll amount is added to the perceived average cost and for the interior expressway tolls, 1% of the toll amount is added.

Either toll option requires an investment of \$100 million in year 2005. If, however, you elect to implement tolling facilities on both the Periférico and the interior expressways,

the initial investment amount is \$175 million. Eighty percent of this investment benefits the Federal District.

Please keep in mind that VKTs on the Periférico and the interior expressways cannot be negative. Also, please realize that in order to analyze the effects of a toll, transportation analysts would normally use a network model. For purposes of this assignment, however, assume that the functions described above are sufficient. Lastly, remember that you are dealing with flows on two distinct parts of the MCMA network: the tolled roads' flows and the region-wide flows. Both the amount of VKT on the toll roads and on the roads region-wide is a function of the toll amount.

- Option 6: ITS/operations investment

As with the tolling option, the ITS and operations technologies option requires an investment be made in 2005. The investment amount is \$500 million. Because of the ability of ITS to improve management and utilization of highway capacity, this policy will have the effect of increasing the annual rate of capacity growth by 0.5%. Because ITS will also be implemented on the Metro, this policy will simultaneously improve performance of non-road-based transportation; therefore, there will not be any impact on mode choice. Benefits are split 50/50 between the Federal District and the State of Mexico.

- Option 7: Finish the Outer Ring

Portions of the Outer Ring have already been completed, but the entire loop will cost \$2 billion to complete, payable immediately. The effect of this project is to increase the rate of capacity expansion by 2 percentage points (e.g., from the current 2% growth rate to 4%) for all years from 2005-2020. While improving capacity for all road-based vehicle travel, this option will not impact Metro mode choice because the Outer Ring will serve residents who live too far away from the Metro for it to be a viable option. This capacity increase will not impact the mode share of road-based modes either. Seventy percent of the remaining portions of the Outer Ring will benefit the Federal District. The remaining 30% will benefit the State of Mexico.

- Option 8: Suspend the Metro fare increase

The Metro price will increase to \$0.40 in 2006 and is scheduled to increase to \$0.60 in 2011. However, prior members of the Special Conference fashioned a deal with the leaders of the Metro. In exchange for a \$1 billion subsidy to the Metro, payable as a lump sum in 2011, the Metro has agreed to reduce the fare increase in 2011 by 10 cents

to \$0.50. Along with this option, the fare will remain at \$0.50 through 2020. In addition, the deal stipulates that the Metro is not eligible for further subsidies from the Special Conference. Seventy percent of this subsidy favors the Federal District, with the State of Mexico seeing 30% of the benefit.

- Option 9: Manufacturing investment in the State of Mexico

This requires an immediate investment of \$1.5 billion in various industries, including textiles, petroleum, and vehicle manufacturing. By directly investing in industry that will bring greater employment to the State of Mexico, you will simultaneously bring jobs closer to the workers. As a result, this investment will reduce PKT by 1% in 2010, when the impact will begin to be felt. Ninety percent of the investment will benefit the State of Mexico.

- Option 10: Convert the bus system to bus rapid transit

This option requires a capital investment of \$1.5 billion, payable immediately. IVTT for the bus option will decrease by 50% in 2011 due to faster speeds of the rapid buses. The cost of bus will hold constant at \$0.75 through 2020 because operating costs will decrease substantially. Lastly, because BRT utilizes newer, cleaner buses, emission factors will decrease by one percentage point more than already forecast for each year from 2011-2020. The benefits are split 50/50 between the Federal District and the State of Mexico.

- Option 11: Subsidize purchase of new natural gas trucks

Each new truck will cost \$200,000. There are currently about 400,000 trucks on the roads in the MCMA. You may purchase as many as 2,000 NG trucks in bundles of 200. Purchases must be made before 2010. Each bundle of 200 new NG trucks replaces 200 gas and diesel trucks. Each bundle increases the mode share of NG trucks by 1 percentage point. The benefit is equal for the Federal District and the State of Mexico.

- Option 12: Publicly-owned logistics company

This company will require an investment of \$40 million, payable now, and a subsequent annual cost of \$5 million. The logistics strategies pursued will reduce freight VKT by 1 percentage point for each year from 2015-2020 due to greater utilization of trucks. In addition, the rate of increase of IVTT for all road-based passenger modes (taxi, colectivo, auto, and bus) will decrease to 0.2% beginning in 2015 through 2020. The company will be located and the research and development will all take place within

the Federal District, with negligible impact on the State of Mexico (e.g., all the benefit of this option is for the Federal District).

- Option 13: Construct freight transfer facilities

Each facility costs \$25 million, payable immediately. You may construct as many as 4 facilities. Each facility will reduce the base year freight VKT (2005) by 1 percentage point and the IVTT of all road-based passenger modes (taxi, colectivo, auto, and bus) by 0.1 percentage points from 2006-2020. All facilities are located entirely in the State of Mexico, so 100% of the benefit accrues to the State of Mexico.

- Option 14: Invest in railroads

An immediate investment of \$1 billion is required to turn the tide of declining rail usage. By investing now, the 5% annual decline in mode share for the period 2006-2015 will become an increase of 1%. For 2016-2020, the decline of 2% will disappear and mode share will remain constant.

Appendix I: References

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