Coordinated Transportation and Land Use Planning in the Developing World – The Case of Mexico City

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ABSTRACT

Much of the research on coordinated transportation and land use methods such as Transit Oriented Development (TOD) has focused on the developed world, particularly the United States. This paper examines the opportunities and challenges for such policies in the developing world, and argues that these policies might have greater benefits in the developing world than in the developed world. Mexico City is used as a case study.

In the developing world, where cities are growing rapidly and car ownership is still low, TOD provides an opportunity to design the urban form to be transit-oriented. Low-income people can thus be served by cheaper high capacity transit, spend less of their income on transportation and have better access to jobs. They will make fewer and shorter trips by informal low capacity transit, reducing congestion and pollution. In the long term, TOD may slow down motorization and mitigate its effects.

Mexico City faces a crisis of mobility, environment and equity. However, it has many of the prerequisites for TOD. It has the densities, an extensive Metro system, and metropolitan planning organizations. Opportunities for coordinated transportation and land use planning there include station area development, downtown redevelopment, real estate development along a proposed suburban rail line, and a policy of building new affordable housing within walking distance of high capacity transit. The greater the geographical scope of each option, the more government involvement is required, and the larger its potential positive impact. An estimate of environmental benefits is made.

ANTI-SPRAWL MEASURES AND TRANSIT-ORIENTED DEVELOPMENT (TOD) IN THE DEVELOPED WORLD

In the United States, planners in recent decades have sought to contain suburban sprawl and its negative social, economic and environmental effects. A series of interrelated policies and ideas have been developed, including downtown revitalization, urban growth boundaries, New Urbanism, "Smart Growth" and Transit-Oriented Development (TOD). These policies share a desire to use existing land resources more efficiently, reduce auto trips, promote non-motorized travel (walking and biking), and increase transit ridership.

The three main principles of TOD are the "Three D's": Density of residents and jobs near transit stations; Diversity of land uses (residential, commercial) near stations; and Design, i.e. urban design elements that make the station more integrated with the surrounding area and more accessible to pedestrians and bicyclists. (1)

A related concept is Transit-Adjacent development (TAD), which refers to development that is close to transit but does not meet all the criteria defined by the "Three D's", especially the urban design elements. The differences between TOD and TAD are more evident in suburban areas, where densities of population and buildings are lower. In a suburban setting, station accessibility cannot be taken for granted. Station planners have to pay more attention to design elements like sidewalks, bicycle paths and the location, size and shape of parking lots, in order to facilitate pedestrian access to the station and integrate it into surrounding development. Real estate developers there must ensure that their developments have convenient access to the transit station. In large cities, where densities are higher and more buildings are clustered in the immediate vicinity of transit stations, the differences between TOD and TAD tend to blur, since urban transit stations tend to be more easily accessible than suburban stations. Of course, design elements are still important, for example in cities with harsh climates, like Montreal and Toronto, where Metro stations are connected to adjacent buildings via underground passages, but their effect on transit ridership is smaller.

TOD can work given the following conditions: (2)

- An extensive transit system that covers a large part of the city
- Government organization with planning and taxation powers concentrated above the level of the single town (i.e. at the metropolitan or regional level)
- Government incentives to developers
- Most importantly, a strong local economy and real estate market

TOD is a controversial topic in the US, with critics arguing that the required population densities would be higher than what most Americans would tolerate, and that some measures advocated by TOD supporters and New Urbanists, like mixed land uses and a grid street pattern, would actually encourage auto use.

In the US, recent efforts at TOD have succeeded mostly at the single transit station level, and have not made an impact at the metropolitan level. Many Americans still live in auto-oriented suburbs, and do not even work in the city centers that are served efficiently by high-capacity transit. In Washington, DC there are several successful examples of TOD at the station level, such as Ballston, Virginia, on the Orange Line of the Metro. (1) However, if TOD only occurs at one or two stations, it will not have a significant effect on transit use, since few destinations are accessible by transit. That is one of the reasons why single-line transit systems often have disappointing ridership.

In Europe, the situation is somewhat better for TOD. Gasoline is more expensive. Central governments have more power, are more directly involved in the planning process, and invest more money in transit. While suburban sprawl exists there as well, auto use tends to be lower, and transit and non-motorized travel have higher mode shares. Greater Stockholm, with its planned communities and high transit mode share, is an example of successful TOD in Europe. (3)

THE PROSPECTS FOR COORDINATED TRANSPORTATION AND LAND USE PLANNING IN THE DEVELOPING WORLD

There is relatively little research about coordinated transportation and land use planning in the developing world. Most research on TOD, Smart Growth and related ideas has focused on developed countries, especially the United States.

In the developing world many people are poor and do not own automobiles. The cities are growing rapidly, and many of the poorest people live on the outskirts, where they depend on expensive informal low-capacity transit, and usually spend a greater percentage of their income on transportation than people with high income. This diminishes their economic opportunities. Mixed land uses still prevail in the centers of the cities, including apartments, commerce (both formal and informal), and in some places light industry.

These conditions also present opportunities for TOD and other methods of coordinated transportation and land use planning. With proper planning and investment, the urban form of rapidly growing cities can be designed to be transit-oriented. This can slow down the onset of motorization and sprawl, and mitigate their effects when they do occur, so that transit and non-motorized transportation maintain relatively high mode shares even after per capita income has risen to near-Western levels. TOD can also have beneficial socio-economic and environmental effects, by concentrating the population along corridors served by high-capacity transit, which has lower operating costs and emissions per seat, and can charge lower fares.

Since cities in the developing world are growing rapidly, it is possible to implement TOD citywide, along a significant part of the transit system (often as it is being built). This is much more difficult to do in the pre-established cities of the developed world, where most of the neighborhoods and transportation infrastructure are already in place and are more difficult to change. Examples of system-wide TOD include Tokyo after World War II, and Curitiba, Brazil in the 1970s and 80s. Implementing TOD on a system-wide scale can significantly increase the attractiveness of transit, since it greatly increases the number of possible origins and destinations that are accessible by a combination of transit and walking. The combination of dense, mixed land uses near stations and pedestrian-friendly station areas on a system-wide scale gives people who live near transit a much larger choice of destinations.

Although the opportunities are great, there are some serious barriers to TOD in the developing world, most of them institutional. Planning institutions are less developed and have fewer resources than their counterparts in the developed world, and often cannot afford to collect much of the data required to inform the planning process. Interdisciplinary planning and metropolitan planning are often poorly developed. Corruption and cronyism are often a problem. Where zoning codes exist, enforcement is sometimes lax or nonexistent.

Another major obstacle is the high cost of infrastructure to support TOD. Even cities in the developed world often have difficulty in obtaining financing for major transit investments. In the developing world, the situation is often worse. Cities spend large amounts of money on a single rail line, which fails to attract adequate ridership because it does not reach enough people and destinations. However, less-expensive technologies like bus rapid transit (BRT) allow cities in the developing world to develop extensive, affordable transit systems.

Can TOD be successful in the developing world? Curitiba, Brazil is a prime example of coordinated transportation and land use planning on a citywide level. This city has been dominated for 20 years by Jaime Lerner and his team of architects and planners. It has a strict zoning code that concentrates growth along transit corridors and prohibits high densities elsewhere, and this code is enforced. It provides incentives for developers to contribute to the construction of low-income housing. It also has an efficient bus rapid transit system that approaches the performance of a metro system at a fraction of the cost. While Curitiba is a lot smaller and less complex than Mexico City and other major cities in the developing world, it still offers valuable lessons, especially its use of zoning and the attention given to equity issues. (3) Bogotá, Colombia, a city of 7 million people, is following in Curitiba’s footsteps in giving priority to transit and pedestrians over the automobile, creating a bus rapid transit system and constructing sidewalks.

While no TOD has yet occurred, the policies initiated by former mayor Enrique Peñalosa are grounded in the realization that an auto-oriented urban form is inequitable and unsustainable in such a large developing-world city.

THE PROSPECTS FOR COORDINATED TRANSPORTATION AND LAND USE PLANNING IN MEXICO CITY

Mexico City, the capital of Mexico, is one of the world's largest cities. It is situated in a valley at an altitude of 2,200 meters amidst the volcanic mountains of central Mexico. The size of the Mexico City Metropolitan Area (MCMA) is 5,294.42 km^2, of which 1,483.23 km^2 are in the Federal District (Distrito Federal – DF), and 3,811.19 km^2 are in the surrounding State of Mexico (Estado de Mexico – EM). In 1995, the population of the MCMA was 16,920,332, of whom 8,489,007 lived in the DF, and 8,431,325 in the EM. The MCMA houses about 10% of the population of Mexico. (4) Administratively, the MCMA includes the 16 *delegaciones* (boroughs) of the DF, 28 *municipios* (towns, municipalities) in the EM, and 1 municipio in the State of Hidalgo. The MCMA is part of a larger region, called the Megalopolis, which includes parts of several states: Mexico, Hidalgo, Morelos, Tlaxcala, Puebla, and Querétaro. Their capitals, respectively, are Toluca, Pachuca, Cuernavaca, Tlaxcala, Puebla, and Querétaro, and they are known as the *corona*, or "crown" of cities surrounding Mexico City. Several of these cities, particularly Puebla, are large metropolises in their own right.

Mexico City's altitude, location, land use patterns and increasing auto ownership combine to create a severe air pollution problem. Mexico City is located in a bowl, surrounded by high mountains from three directions, trapping the pollution inside the valley. Unfortunately, the fourth side (north of downtown) is where the heavy industry is located, further exacerbating an already bad situation.

Automobile ownership is growing in the MCMA. Most households with a combined monthly household income of more than 5 minimum salaries (the minimum salary in Mexico is about 4 USD per day) own a car. People at this level of income are still a minority (36% of all households in the MCMA), but they are a growing one. (5)

Mexico City used to have an excellent bus system. However, during the economic crisis of the 1980s, the neo-liberal government greatly reduced its investment in public transportation, and gave licenses to operators of colectivos, a form of jitney service (informal transit). The colectivos had higher fares, but also had higher frequencies, and more flexible routes and stops than the buses. With their superior level of service and aggressive business practices, they quickly destroyed the bus system, reducing its mode share of passenger trips in the DF from 42.3% in 1986 to 1.8% in 1998! During the same period, the colectivo mode share in the DF grew from 5.5% to 58.6%. (6) There are also several trolleybus lines and one light rail line, but their mode shares are currently negligible.

Mexico City has an extensive Metro system with the lowest operational costs of any major world Metro. It transports 4.5 million daily passengers, and ridership on its busiest lines approaches 1 million daily passengers. However, it does not extend deeply into the EM, where half the population lives. Almost all the lines terminate at the DF-EM boundary, and the stations there are the busiest in the system. Many passengers transfer from colectivos to the Metro at these stations. The expansion of the system can reduce the use of colectivos and their emissions, and reduce the travel expenses of low-income people living on the outskirts. The downtown is still the main destination of trips in the MCMA, and the busiest lines are those that pass through it. However, due to disagreements between the DF and the EM over financing of Metro expansions, the next phase of expansion will occur exclusively in the DF, even though a strong argument can be made that the EM is where expansion is needed most. The recently opened line B (see Figure 1), which does go into the EM, has so far performed very well, and has eliminated some colectivo trips.

Another major problem is that the Metro is used primarily by the poor. Middle and high-income people regard the Metro as crowded and unsafe. Although the poor are the majority of the population in the MCMA, the fact that other people avoid the Metro means that there is less political willingness to invest in it. The government would rather invest in highway projects that cater to the interests of auto owners. While there is an ambitious Master Plan for the Metro and light rail, and some parts of it may be built in the near future, it is doubtful whether it will be completed on schedule in 2020.

Mexico City has many of the prerequisites for TOD. It is densely populated, despite the lack of high rises, although it could perhaps be denser, particularly the downtown areas. The population density in the MCMA is 11,587 people per square kilometer, compared to 10,313 people/km^2 in New York City and 3,077 people/km^2 in Los Angeles. This density is remarkably uniform across most of the inhabited parts of the MCMA. The center of the city has mixed land uses. In fact, the informal commerce present at many Metro stations provides many of the benefits of mixed land use, since the poor, who are the majority of Metro riders, can use it for shopping on their way to and from work. While urban design around Metro stations is not very developed, most stations are easily accessible from the surrounding neighborhoods.

The MCMA has some of the institutional structure required to support coordinated transportation and land use planning, but more needs to be done. Zoning in the DF is in the hands of the delegaciones, while the DF government collects property taxes and can veto zoning decisions. This situation makes it easier for the DF government to pursue a citywide policy of coordinated transportation and land use planning. If the delegaciones had the power to collect property taxes, they would compete with each other, pursuing their own interests (e.g. attracting big office development and high-income housing) at the expense of the interests of the rest of the city (e.g. mobility, accessibility, equity, environment).

There is insufficient interdisciplinary planning. Location decisions for public housing, schools, hospitals, etc. are made without sufficient consideration to access to public transportation. The urban development trends in the MCMA highlight the need for greater coordination between transportation and land use planners, as well as between the DF and the EM. Recent urban growth in the MCMA has concentrated in the EM and outer delegaciones of the DF, while heavy industry has been moving out of the MCMA to other parts of the country. American-style shopping malls and office parks have been built in the more affluent western areas, often without adequate transit access. The EM's ambitious transportation plan includes intercity roads that would bypass the DF, as well as a new airport in the suburb of Texcoco (a project which has recently been suspended due to objections by local residents). These will have profound impacts on the urban form of the MCMA, and could lead to further sprawl, which in turn could result in longer and more numerous colectivo and automobile trips and diminish the effectiveness of the Metro system. Coordinated transportation and land use planning at the metropolitan level is the key factor in maintaining control over the urban form of the MCMA.

The DF government has recently imposed curbs on development anywhere outside its four central delegaciones. However, this merely causes more development to occur across the border in the EM, where no such curbs exist. This highlights the need for planning at the metropolitan level. While there is a metropolitan transportation planning organization (COMETRAVI), it has little power. A metropolitan planning organization with more powers (e.g. zoning) may be able to control the urban form of the metropolitan area and facilitate the provision of high-capacity transit, while taking into account the economic interests of both the DF and EM.

There are many opportunities for coordinated transportation and land use planning in Mexico City. They are detailed below, summarized in Table 1 and shown in Figure 1. They include both full-scale TOD, as well as broader measures aimed at increasing transit adjacency.

The Metro can serve as a backbone for efforts to redensify the steadily depopulating downtown and create infill development there, thereby contributing to the containment of sprawl. Station-area TOD, like that done in Tokyo and Hong Kong, is also an opportunity, although it cannot be done in the larger stations without the consent of the powerful informal commerce sector.

There are opportunities for TOD along a proposed suburban rail line in the northwestern part of the MCMA, which will be privately operated. The suburban rail line will run through decaying industrial areas and near middle-income neighborhoods. It provides an opportunity to create a transit corridor along which many people can live and work, centered around a new transit system that middle-class people might be willing to use. This corridor will feature the high densities, mixed land uses and urban design elements typical of TOD. Real estate development in and around Buenavista station in the DF (the southern terminus of the line) is already being considered, and it can be expanded to the rest of the alignment and planned so that it is integrated into the new transit system.

Affordable housing presents a big opportunity. Ideally, the government could require that all new government-sponsored affordable housing projects in the MCMA be located near the Metro, light rail, or suburban rail. There is currently a shortage of affordable housing in Mexico City, but affordable housing will be necessary in order to densify low-income neighborhoods and encourage people to return to the central delegaciones. There are government housing funds that are supposed to help the poor buy houses, but their minimum income requirements are often too high for most poor people, and the funds are used more often by middle-income people. However, a new concept, the Location Efficient Mortgage (LEM), could help here. The LEM, which is now offered in several American cities, is based on the assumption that people who live in walkable, transit-oriented neighborhoods spend less money on transportation, and thus can afford a higher debt-to-income ratio. These people can become eligible for mortgages, or can afford higher mortgages than they could otherwise. Low-income Mexicans probably spend more of their money on transportation than lower middle-class Americans, and could probably benefit from LEMs if they were offered in Mexico City.

The various options require different levels of institutional effort and commitment. A policy of locating all new affordable housing near the Metro probably has the highest potential impact, but is also the most expensive, requiring a large investment in affordable housing and subsidized mortgages. Downtown redevelopment requires a downtown redevelopment plan and incentives (tax breaks, construction bonuses, parcel assembly) for developers. TOD along the suburban rail alignment requires incentives as well as a corridor plan. Station-area development at Metro stations probably requires the least institutional effort but can still have significant impact if done throughout the Metro system.

Each option can have some local impact without extensive involvement by the municipal governments of the MCMA, but can have larger impacts if the government does become involved:

- Government commitment to building affordable housing, and locating most or all of it near Metro, light rail or suburban rail stations could lead to a significant increase in Metro ridership. If this housing is located near underutilized Metro lines, it could increase ridership on those lines and perhaps help alleviate congestion on the saturated ones.
- Downtown redevelopment is already occurring, although it is mostly confined to commercial high rises and hotels, but with government involvement in the form of affordable housing and incentives for mixed use, it can slow down the depopulation of the central city.
- Some development will probably happen along the suburban rail alignment, for example in the Buenavista terminal in the DF. However, metropolitan coordination in the form of a joint DF-EM suburban rail corridor plan can significantly increase the potential for the development of a high-density, mixed-use transit-oriented corridor along the suburban rail alignment. Such a corridor plan can also ensure that development along the corridor will be in the form of TOD, rather than TAD.
- The addition to the Metro Master Plan of a detailed study of real estate opportunities in Metro stations, together with aggressive marketing of these opportunities for TOD, can improve the chances of their development, bring money to the STC (the DF-owned company that operates the Metro) and reduce its dependence on subsidies from the DF government.

If more people can be concentrated near Metro stations through an expansion of the system and a policy of locating housing and other developments near it, the equity and environmental effects can be considerable. People who have the option of using the Metro without a colectivo feeder trip have significantly lower transportation expenses. They are not affected by road congestion, and can reach their destination more quickly and predictably. This could increase their job opportunities. In short, TOD can be a great force for equity in the developing world. Mexico City's extensive Metro system positions it to take full advantage of this concept.

The ideal urban form created by coordinated transportation and land use planning would preserve the importance of the downtown area and channel development outside that area into corridors served by the Metro, light rail or suburban rail for maximum accessibility by people of all income levels.

On the environmental side, TOD can significantly reduce colectivo-related emissions by eliminating and/or shortening colectivo trips (see next section). However, the most significant environmental effect of TOD is indirect and long-term – creating a transit-oriented urban form, where people will continue using high-capacity transit (at least for the trip to work) even after they can afford an automobile, thereby mitigating the increase in pollution that accompanies motorization. That was one of the main achievements of Curitiba, where the majority of the population still commutes to work by bus, even though it has Brazil's second-highest auto ownership rate. (3) Much of that was due to the fact that Curitiba was able to control its growth and was able to control the supply of parking spaces. As part of a policy of transit-oriented affordable housing, Mexico City can include limitations on parking supply before the residents can afford automobiles, thereby averting some of the political backlash.

It is often claimed that further investments in public or private transportation in the MCMA would only attract more migrants to the MCMA and will worsen its already acute problems. There have been suggestions that instead of making such investments, people should be encouraged to migrate to the "corona" cities around Mexico City. This could be a good way to alleviate many of the socio-economic and environmental problems of the MCMA. More research about the costs, benefits and feasibility of this is necessary, but is beyond the scope of this paper. It should be noted that a substantial part of the internal migration in Mexico in the last decade has been to cities near the US border rather than to the central region of Mexico.

TOD is not intended to attract more people into the MCMA. As incomes rise and the existing housing stock deteriorates (particularly in low-income neighborhoods that were originally informal settlements), many current residents of the MCMA may seek new housing that is more comfortable and built to a higher standard (while earthquakes are a problem, densification does not necessarily require very tall buildings, and can be achieved by using urban land more efficiently). The policies outlined above represent a way to channel these people into areas adjacent to high-capacity transit such as the Metro and suburban rail.

TOD probably cannot turn back the clock for people who already own a car. This is because the Metro is perceived as a mode for the poor (which is currently largely true), and because the auto is such a status symbol in Mexico. Middle class people do not return to transit unless congestion becomes extreme (the case in places like New York, and a definite possibility in the MCMA). A possible exception might be the proposed suburban rail, whose first line will pass through the highly (and increasingly) congested northwestern entry to the DF. TOD cannot cure congestion, but it can mitigate the amount of future congestion by slowing down the pace of motorization, or at least motor vehicle use.

TOD could potentially address the issues of environment, mobility, accessibility and equity facing Mexico City. TOD can be an important component in an overall pollution reduction strategy. Pollution reduction strategies that depend only on reducing tailpipe emissions will not solve congestion and equity problems. Even if clean, zero-emission automobiles and colectivos could be introduced, they will just end up stranded in clean, zero-emission gridlock in the not-so-distant future. TOD will enhance accessibility by ensuring that important trip destinations are located near high capacity public transportation, and will increase the probability that commuters will choose to travel by high capacity modes.

TOD is, of course, a long-term policy and cannot be expected to deliver immediate results, but a series of changes to the planning culture in the MCMA could help sow the seeds for a transit-oriented urban form that would be both socially and environmentally more sustainable.

QUANTIFYING THE EFFECTS OF METRO EXPANSION AND TOD

The following section examines the effects of Metro expansion. It begins by illustrating the effects of simply having more people live near the Metro and light rail, before any deliberate efforts are made at TOD or other forms of coordinated transportation and land use. It then adds the possible effects of TOD on the number of people living near the Metro and light rail. In this section the term “TOD” was used as shorthand to refer to all the policies described in the previous section, including both full-fledged TOD (e.g. the suburban rail corridor) and policies aimed at increasing transit adjacency (e.g. affordable housing within walking distance of the Metro).

Currently, approximately 1.3 million people live within 500 meters of a Metro or light rail station, and it is assumed in this analysis that they can access the Metro by walking, without a feeder trip by bus or colectivo. This is based on a rough measurement of the area within 500 meters of a Metro station multiplied by the population density, which, as stated above, is almost uniform across the entire metropolitan area (density figures for Mexico City are calculated based on total *urbanized* area of all delegaciones and municipios, not on their *total* land area). If the government carries out the entire Master Plan for the Metro and light rail, this number will increase to about 3 million even if no TOD occurs. The 500-meter radius is often used in the context of TOD in the developed world. Poor people in a developing country can be assumed to be willing to walk more than 500 meters to get to a Metro station and travel cheaply. The number of people living within one kilometer of a Metro or light rail station would be perhaps three or four times as large as that for a radius of 500 meters. Of course, proximity to the Metro does not guarantee its use, but the larger the system, the more destinations it serves, and the more useful it becomes to people.

The expansion of the Metro can have two effects on colectivo ridership. First, some people stop using the colectivos altogether or use them less frequently. Second, since the Metro network extends further out, colectivo feeder trips from areas still not served by the Metro become shorter, with the result being a decline in average colectivo trip length.

For this analysis, several assumptions were made:

- The Metro Master Plan has been completed, and 3 million people now live within walking distance of the Metro (using the conservative assumption that walking distance is only 500 meters).
- Before the completion of the Master Plan, most of the 3 million people either used the colectivo exclusively, or a combination of Metro and colectivo. The limited reach of the Metro made exclusive use of the Metro infeasible for most of them.
- Due to the wide reach of the Metro after the expansion, it is very attractive to passengers, and some of the 3 million people have abandoned the colectivo completely in favor of the Metro.
- The Metro has enough capacity to handle the extra demand.
- The number of colectivo vehicle trips drops as well in the face of the decline in demand.
- Colectivo passengers make two daily colectivo trips.
- The number of automobile trips diverted to the Metro is negligible.

A series of calculations was made to determine the reduction in colectivo use under various circumstances. For example, if half the 3 million people abandon the colectivo, and each one of them used to make two daily colectivo trips, 3 million daily colectivo passenger trips are eliminated. This does not mean that 3 million trips are added to the Metro, because some of the eliminated colectivo trips may have previously been part of multimodal colectivo-Metro trips. The average passenger trip length on colectivos in the MCMA is 8.4 kilometers. (7) Multiplying this by 3 million passenger trips and then by 365, 9.198 billion annual passenger-kilometers traveled (PKT) eliminated are obtained. Assuming, based on colectivo passenger capacity and occupancy rates, that there are 13.5 colectivo PKT per colectivo vehicle-kilometers traveled (VKT), and that this ratio remains constant, i.e. that colectivo vehicle trips decline at the same rate that colectivo passenger trips decline, 681 million annual VKT eliminated are obtained. The 1998 emissions inventory provides grams of pollutants per VKT for colectivos (7.57 grams/VKT for HC, 82.63 for CO, 2.61 for NOx, 0.029 for PM_{10}, and 0.115 for SO_2). (8) Multiplying the VKT by these factors yields the emissions eliminated annually, which are then compared to overall colectivo emissions in the MCMA to obtain the percent reduction in each pollutant.

Next, a sensitivity analysis was conducted, and its results are shown in Table 2. The previous calculation was repeated, and the following sensitivities were tested:

- Sensitivity to the percentage of people who completely abandon the colectivos for the Metro.

- Sensitivity to the PKT/VKT ratio. Three cases were compared. In the first case, the ratio remains 13.5, i.e. the reduction in colectivo passenger trips is matched by a reduction in colectivo vehicle trips. In the second case, it was assumed that passenger trips go down faster than vehicle trips, so the PKT/VKT ratio is 20% lower, at 10.8. In the third case, the opposite was assumed, and the PKT/VKT ratio is 20% higher, at 16.2.
- Sensitivity to the number of people living near the Metro and light rail. This was done in order to examine the possible impact of TOD, as well as the possibility that the Metro Master Plan would not be executed in its entirety. This also accounts for the possibility that people would walk more than 500 meters to get to the Metro. A lower bound of 2 million people was set, representing a limited Metro expansion and some TOD, and the upper bound was set at 5 million people, representing full Metro expansion and massive TOD (for example, massive construction of affordable housing near the Metro).
- Lastly, some interactions between the variables to examine best case and worst-case scenarios.

Another possible effect of Metro expansion (with or without TOD) is a reduction in colectivo passenger trip lengths. The effect of Metro expansion on the average colectivo passenger trip length in the entire MCMA was examined, both in areas near the Metro and far from it. In the following example, the average length of a colectivo trip in the MCMA is reduced from 8.4 kilometers to 6 kilometers. According to trip rate estimates in (7) as well as research done by the MIT Mexico City team, it was estimated that there were 11.333 million daily colectivo passenger trips in 2000. This is multiplied by 6 kilometers and then by 365 to get 24.819 billion annual PKT. This is then divided by 13.5 PKT/VKT to obtain 1.838 billion annual colectivo VKT. The same calculation is then done for the current 8.4-kilometer trip length, and the difference between the two is the amount of colectivo VKT eliminated. The same emission factors used in the previous calculations yield emission reductions in both absolute numbers and as a percent reduction in overall colectivo emissions. A sensitivity analysis was conducted, using colectivo trip lengths ranging from the current 8.4 kilometers to as low as 5 kilometers. The results are summarized in Table 3.

The results indicate that Metro expansion and TOD have the potential to eliminate significant amounts of pollutants. Colectivo emissions have the same sensitivity to changes in the proportion of people living near the Metro who use it as they have to changes in the number of people living near the Metro and to changes in colectivo trip length. Colectivo emission reductions are less sensitive to changes in the PKT/VKT ratio than they are to changes in passenger trip rates. The best and worst cases at the end of Table 2 highlight the even greater sensitivity of colectivo emissions to changes in more than one variable at once. If the number of people living near the Metro is increased (through Metro expansion and TOD), and a greater proportion of them choose to take the Metro (due to increased network connectivity created by both the Metro expansion and TOD), the potential for emission reduction is great.

As previously mentioned, these results only represent the direct effects of Metro expansion and TOD. The most significant environmental effect of these policies is indirect – the creation of a transit-oriented urban form that will mitigate the effects of motorization.

RECOMMENDATIONS FOR FURTHER RESEARCH

There is a strong need for more quantitative research on the manner in which transportation, land use and the environment affect each other in the MCMA. SETRAVI, the transportation department of the DF, possesses travel demand software and has GIS data about the transportation system. There is currently no land use – transportation model for Mexico City. The costs of constructing such a model for a city of this size are very large. Nevertheless, the model could be very helpful to planners.

More research is also needed on travel patterns and trip chaining in the developing world, particularly those of low-income people. These are likely to be quite different from those in the developed world. This is important since most land use and transportation models were developed in the developed world, and make many assumptions that might not be valid in the developing world.

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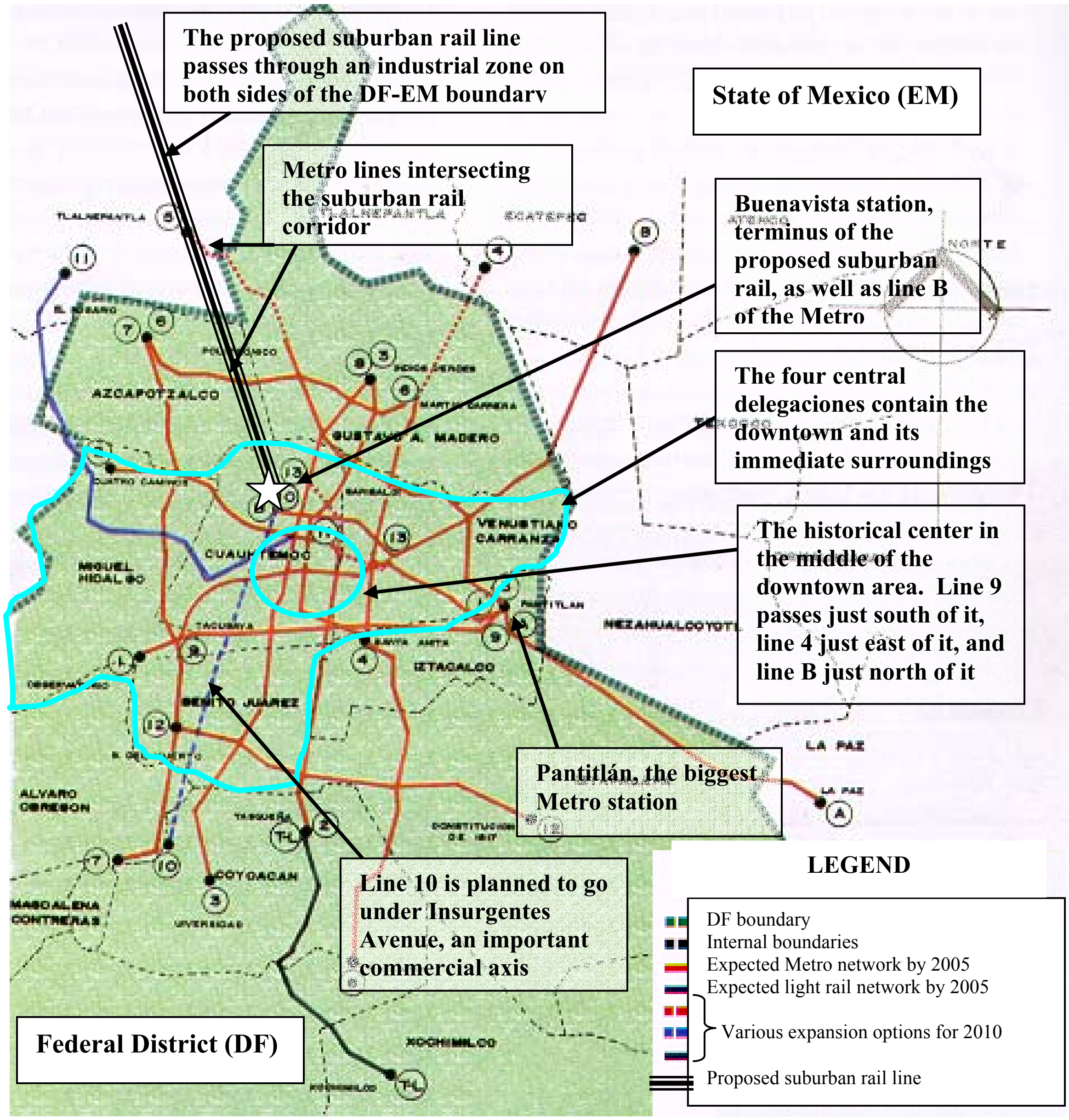

FIGURE 1 Possible Locations for TOD Along the Metro, Light Rail and Suburban Rail in Mexico City
Source of base map: Sistema de Transporte Colectivo, *Plan de Empresa, 2000-2006*, Mexico City, 1999.

TABLE 1 Geographical Scope and Implementation Issues For Coordinated Transportation and Land Use Options in Mexico City

Policy Option	Geographical Scope	Implementation Issues
Affordable housing near Metro and light rail	Station-area, or corridor, or citywide	• Willingness by government or private sector to build affordable housing • For citywide effect, metropolitan coordination is needed • Availability of land • Capacity on Metro
Downtown redevelopment	The four central delegaciones of the DF	• Availability of land • For greater effect, affordable housing is necessary
TOD along suburban rail	Station-area or corridor	• Availability of land • For corridor-wide effect, metropolitan coordination is needed • Private sector interest • High ridership on suburban rail will bolster private sector interest
TOD in and around Metro stations	Station-area	• Availability of land • Private sector interest • At the largest stations, possible confrontation with informal commerce

TABLE 2 Colectivo Emissions Eliminated by Metro Expansion: Sensitivity to Number of Colectivo Trips

Number of people living near the Metro or light rail	Percent of people near Metro who abandon colectivos completely	PKT/VKT Ratio	Annual metric tons of HC eliminated (% reduction in colectivo HC emissions)	Annual metric tons of CO eliminated (% reduction in colectivo CO emissions)	Annual metric tons of NOx eliminated (% reduction in colectivo NOx emissions)	Annual metric tons of PM_{10} eliminated (% reduction in colectivo PM_{10} emissions)	Annual metric tons of SO_2 eliminated (% reduction in colectivo SO_2 emissions)
3,000,000	**10%**	13.5	1,032 (4.8)	11,260 (4.7)	356 (3.4)	4 (5.7)	16 (8.1)
3,000,000	**20%**	13.5	2,063 (9.5)	22,519 (9.5)	711 (6.8)	8 (11.5)	31 (16.2)
3,000,000	**30%**	13.5	3,095 (14.3)	33,779 (14.2)	1,067 (10.2)	12 (17.2)	47 (24.2)
3,000,000	**40%**	13.5	4,126 (19.0)	45,039 (19.0)	1,423 (13.6)	16 (22.9)	63 (32.3)
3,000,000	**50%**	13.5	5,158 (23.8)	56,299 (23.7)	1,778 (17.0)	20 (28.6)	78 (40.4)
3,000,000	**60%**	13.5	6,189 (28.5)	67,558 (28.5)	2,134 (20.4)	24 (34.4)	94 (48.5)
3,000,000	**70%**	13.5	7,221 (33.3)	78,818 (33.2)	2,490 (23.8)	28 (40.1)	110 (56.5)
3,000,000	**80%**	13.5	8,252 (38.0)	90,078 (38.0)	2,845 (27.2)	32 (45.8)	125 (64.6)
3,000,000	**90%**	13.5	9,284 (42.8)	101,337 (42.7)	3,201 (30.6)	36 (51.5)	141 (72.7)
3,000,000	50%	**16.2**	4,298 (19.8)	46,915 (19.8)	1,482 (14.2)	16 (23.9)	65 (33.7)
3,000,000	50%	**13.5**	5,158 (23.8)	56,299 (23.7)	1,778 (17.0)	20 (28.6)	78 (40.4)
3,000,000	50%	**10.8**	6,447 (29.7)	70,373 (29.7)	2,223 (21.3)	25 (35.8)	98 (50.5)
2,000,000	50%	13.5	3,438 (15.8)	37,532 (15.8)	1,186 (11.3)	13 (19.1)	52 (26.9)
2,500,000	50%	13.5	4,298 (19.8)	46,915 (19.8)	1,482 (14.2)	16 (23.9)	65 (33.7)
3,000,000	50%	13.5	5,158 (23.8)	56,299 (23.7)	1,778 (17.0)	20 (28.6)	78 (40.4)
3,500,000	50%	13.5	6,017 (27.7)	65,682 (27.7)	2,075 (19.8)	23 (33.4)	91 (47.1)
4,000,000	50%	13.5	6,877 (31.7)	75,065 (31.6)	2,371 (22.7)	26 (38.2)	104 (53.9)
4,500,000	50%	13.5	7,737 (35.6)	84,448 (35.6)	2,667 (25.5)	30 (43.0)	118 (60.6)
5,000,000	50%	13.5	8,596 (39.6)	93,831 (39.6)	2,964 (28.4)	33 (47.7)	131 (67.3)
2,000,000	**10%**	**16.2**	573 (2.6)	6,255 (2.6)	198 (1.9)	2 (3.2)	9 (4.5)
3,000,000	**50%**	**13.5**	5,158 (23.8)	56,299 (23.7)	1,778 (17.0)	20 (28.6)	78 (40.4)
5,000,000	**90%**	**10.8**	19,341 (89.1)	211,120 (89.0)	6,669 (63.8)	74 (100.0)	294 (100.0)

TABLE 3 Colectivo Emissions in the MCMA: Sensitivity to Passenger Trip Lengths (Assuming 13.5 PKT/VKT)

Colectivo passenger trip length	Annual metric tons of HC eliminated (% reduction in colectivo HC emissions)	Annual metric tons of CO eliminated (% reduction in colectivo CO emissions)	Annual metric tons of NOx eliminated (% reduction in colectivo NOx emissions)	Annual metric tons of PM_{10} eliminated (% reduction in colectivo PM_{10} emissions)	Annual metric tons of SO_2 eliminated (% reduction in colectivo SO_2 emissions)
5.0	7,886 (36.3)	86,083 (36.3)	2,719 (26.0)	30 (43.8)	120 (61.8)
5.5	6,727 (31.0)	73,424 (31.0)	2,319 (22.2)	26 (37.3)	102 (52.7)
6.0	5,567 (25.6)	60,765 (25.6)	1,919 (18.4)	21 (30.9)	85 (43.6)
6.5	4,407 (20.3)	48,105 (20.3)	1,519 (14.5)	17 (24.5)	67 (34.5)
7.0	3,247 (15.0)	35,446 (14.9)	1,120 (10.7)	12 (18.0)	49 (25.4)
7.5	2,088 (9.6)	22,787 (9.6)	720 (6.9)	8 (11.6)	32 (16.3)
8.0	928 (4.3)	10,127 (4.3)	320 (3.1)	4 (5.2)	14 (7.3)
8.4	0	0	0	0	0