

# TRAFFIC CONGESTION

**THE PROBLEM AND  
HOW TO DEAL WITH IT**

*Alberto Bull  
Compilador*



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**Alberto Bull**  
Editor



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## **SUMMARY**

### **Congestion: a serious and worsening problem**

Traffic congestion has been increasing in much of the world, developed or not, and everything indicates that it will continue to get worse, representing an undoubted menace to the quality of urban life. Its main expression is a progressive reduction in traffic speeds, resulting in increases in journey times, fuel consumption, other operating costs and environmental pollution, as compared with an uninterrupted traffic flow.

Congestion is mainly due to the intensive use of automobiles, whose ownership has spread massively in Latin America in recent decades. Private cars have advantages in terms of facilitating personal mobility, and they give a sensation of security and even of heightened status, especially in developing countries. They are not an efficient means of passenger transport, however, since on average at rush hours each occupant of a private car causes about 11 times as much congestion as a passenger on a bus.

The situation is further aggravated in the region by problems of road design and maintenance in the cities, a style of driving which shows little respect for other road users, faulty information on traffic conditions, and unsuitable management by the responsible authorities, which are often split up among a host of different bodies.

The cost of congestion is extremely high. According to conservative calculations, for example, increasing the average speed of private car journeys by 1 km/hr and that of public transport by 0.5 km/hr would give a reduction in journey times and operating costs worth the equivalent of 0.1% of the gross domestic product (GDP) (Thomson, 2000b).

The harmful effects of congestion are suffered directly by the vehicles that are trying to circulate. They are not only suffered by motorists, however, but also by users of public transport –generally lower-income persons—who not only take longer to travel from one place to another but also have to pay higher fares on account of congestion. All city-dwellers are also adversely affected, in terms of a deterioration in their quality of life through such factors as greater air and noise pollution and the negative long-term impact on the healthiness and sustainability of their cities, all of which makes it vitally necessary to keep congestion under control.

### **Make a start with measures affecting supply**

The most logical approach is to tackle congestion through measures affecting the supply of transport, i.e., the availability and quality of the transport infrastructure, vehicles and their management, since this represents an increase in the capacity for travel.

There are many shortcomings in the current urban road systems which need to be put right: it is necessary to improve the design of intersections, mark roads properly and provide them with suitable signs, and correct the operating cycles of traffic lights, for example. Another possible measure would be to make the traffic flow in the main avenues reversible at rush hours. These measures can relieve congestion considerably and do not usually cost much, the main requirement being a knowledge of traffic engineering.

The construction of new roads or the widening of existing ones should not be ruled out, when appropriate and feasible within the context of a harmonious form of urban development which provides for adequate spaces for pedestrians and preserves the architectural heritage. It should be borne in mind, however, that building more and more roads, under- and overpasses and urban expressways may be counter-productive in the medium and long term and may actually make congestion even worse, as we have unfortunately seen in the cases of some cities which adopted this strategy.

Big savings may be obtained through a system of traffic lights run from a central computer. The rather high cost of this system in the view of many municipalities might make it advisable to set about this programme initially in several stages and only in certain sectors of the city, beginning with the progressive replacement of obsolete traffic lights by newer ones suited to the necessary technology. The application of this system in areas of heavy traffic would show off its virtues and obtain citizen support for its wider use.

Another very real need is to organize a public transport system which provides effective service. Substantial benefits are provided, not only for buses but also for private cars, by segregated lanes for public transport. It may also be necessary to reorganize the bus lines into trunk and feeder lines, to give them certain preferential traffic rights, and to improve the quality of the buses used and the business capacity of their operators. Buses of a higher standard than those generally in service may also have a useful role to play, especially if their operating timetables and frequencies allow them to offer a viable alternative to private car users.

A significant contribution can be made by transport systems similar to above-ground subway lines, organized on the basis of buses running in their own segregated lanes, with regular journey frequencies, centralized control, boarding and alighting of passengers only at designated stations, and a requirement that passengers must purchase their tickets before boarding the bus. Although installing these systems is a complex matter and the construction of the necessary infrastructure will assuredly need the contribution of public



resources, the excellent results obtained in Curitiba, the Quito trolleybus system and the Transmilenio public transport system in Bogotá fully justify this solution, which costs only a fraction of the construction of an underground subway system.

It is important that public transport should be improved in order to provide a rapid service of decent standard and thus maintain the present proportion of journeys made by this means. In developing countries, over half of all journeys –and as much as 80% in some cities—are made by public transport.

If well designed and executed, measures affecting supply offer an interesting potential for tackling congestion. Even so, it is necessary to incorporate other measures, especially respecting demand, to be able to solve the imbalances in infrastructure use and aid in achieving an acceptable balance for the community as a whole.

### **Measures aimed at demand also have a role to play**

The aim of these measures is to persuade a substantial number of private car users travelling at rush hours or in areas of heavy traffic to use higher-density forms of transport, use non-motorized means of transport, or change the times at which they travel.

Some measures may involve the application of regulations and restrictions. Others may provide economic rewards or disincentives for adopting forms of conduct that reduce congestion. Both types of measures need to be considered for a better overall result, since economic measures may not be fully effective, while those involving regulations may be vulnerable if the controls are weak.

Substantial results can be achieved through the rationalization of parking spaces, since their availability and cost condition access by private car users. Permanent or daytime prohibition of parking on the main streets, charges for parking on other streets, the regulation of paid parking in private parking lots and free parking offered by institutions and firms to their workers or to the public, economic incentives for not going to work by car, and intermediate parking lots for leaving cars and continuing the journey in public transport are potentially useful measures if applied in the right places and the right way. Some of them may also generate income for the municipalities.

Staggering the starting hours of activities relieves congestion somewhat, as it spreads the morning rush hour over a longer period, while restrictions on vehicle use can take a substantial part of the total number of vehicles out of circulation. The application of such restrictions only in the most congested sectors or times, as for example in central areas during the morning and evening rush hours, may have more lasting effects than their more general application, since it will give less incentive to buy extra cars to get round the restrictions. Another form of restriction is to charge differential licence fees depending on whether or not the vehicle can be used every day of the week.

Road use tariffs, which have been proposed by many academics and urban transport officials because they represent an attractive concept for making drivers pay for the costs they cause to society, are the measures which have met with the strongest resistance, especially from private car owners. These measures seem to get results, at least in the short term, but they are questioned from every imaginable angle. They are unacceptable for users, since they require them to pay for moving about in conditions of congestion; there are doubts about how to apply them; there are objections about their effects on areas immediately next to those subject to tariffs; they are accused of being inequitable with regard to persons with fewer resources; it is feared that economic activities in the areas subject to tariffs will be adversely affected; there are doubts about their long-term effects on town planning, because they are an incentive for cities to expand unless there are severe controls on land use; and last but not least, it is claimed that their application would be theoretically inconsistent unless other related prices, such as those of green spaces, are also made subject to the recovery of their marginal cost. It would therefore appear that the likelihood of their application is limited, unless some city (other than Singapore, which has extremely special conditions) manages to put them into effect successfully. They may perhaps be tried out first in developed countries, if the congestion there reaches intolerable levels, no other effective means are seen to exist, and the theoretical and practical doubts that still affect them can be successfully solved.

If carried out permanently ever since childhood, education in proper road use can help to reduce congestion by teaching the population not to drive in an undisciplined manner or fail to show due respect to other road users, whether pedestrians or other drivers. Likewise, pedestrians must also be made to observe traffic rules and cross the street only at suitable places and moments.

Measures affecting demand must be carefully analysed in order to avoid unwanted ill-effects. Over-restrictive regulations can alienate firms and residents and depress some areas of cities.

### **How should the problem be tackled?**

The rapidity with which congestion can reach acute levels in big cities makes it essential for the authorities to take the right approach when seeking to adapt urban transport systems in this respect, both in the case of public transport and in that of private car use in problem areas or times.

The first concern should be to relieve the effects of congestion on those who have little or no responsibility for causing it, by:

- Promoting or recovering the road system's quality of a public good, by facilitating the free circulation of those who do not contribute to congestion, or only do so to a negligible extent. This mostly means providing public transport with clear, unimpeded routes and giving it some degree of priority over other road users, including segregated bus lanes when appropriate in order that it should not be held up by congestion;

- Keeping the emission of pollutants under control; and
- Limiting congestion in order to prevent it from endangering the quality of life and sustainability of cities.

Reducing congestion also has the result of reducing the emission of pollutants that contaminate the air, since in most cities in the world the transport system is one of the main culprits for atmospheric pollution. An integrated strategy for combating these two problems can therefore result in more efficient solutions than the application of isolated measures to combat each of them separately.

Combating congestion entails various amounts of costs. Some must be defrayed by the public bodies that are applying the measures; others affect the population in general, while those related with actions regarding demand affect motorists in particular.

Everything indicates that an effort should be made to apply a set of actions designed to affect both the supply of transport and the demand for it, in order to rationalize public road use. It must be recognized that a style of personal mobility based essentially on the use of private cars is not sustainable in the long term, although this does not necessarily mean that it should be prohibited. Private cars have many uses which make urban life easier, such as facilitating social life, shopping or travelling to distant destinations. Using them every day to go to one's place of work or study in areas of heavy traffic is a different matter, however.

It is therefore necessary to design policies and measures of a multi-disciplinary nature which will make it possible to keep congestion under control, since it is not reasonable to think of eliminating it altogether. In the case of cities in developing regions, while local conditions must always be taken into account, it would seem advisable to give priority to the following measures:

- Rectification of intersections
- Improvement of road markings and signs
- Rationalization of on-street parking
- Staggering of working hours
- Synchronization of traffic lights
- Reversibility of traffic flow direction in some main avenues
- Establishment of segregated bus lanes, together with the restructuring of the system of bus routes

At the same time, it is necessary to establish a long-term strategic vision of how the city should develop which will make it possible to harmonize the needs of mobility, growth and competitiveness, which are so necessary in the world of today, with the sustainability of cities and the improvement of their quality of life. This is a complex task, calling for high professional and leadership qualities on the part of the town planning and transport authorities, and it could perhaps be made easier by the establishment of a single unified transport authority in metropolitan areas.

Keeping congestion under control is an ongoing, never-ending task. Tools exist for this purpose, some of them more effective and some of them more readily accepted than others, but a set of measures which has the support of the local population is needed in order not to run the risk of succumbing in the face of the modern scourge of traffic congestion.

## Chapter I

### **A LIVABLE, COMPETITIVE AND SUSTAINABLE CITY**

#### **1. Congestion: an escalating negative phenomenon**

In recent years, and especially since the early 1990s, the increase in road traffic and in the demand for transport have caused serious congestion, delays, accidents and environmental problems, above all in large cities. Traffic congestion has become a veritable scourge which plagues industrialized countries and developing nations alike. It affects both motorists and users of public transport, and as well as reducing economic efficiency it also has other negative effects on society. The disturbing thing is that this expression of modern times has been intensifying, without any sign of having a limit, thus becoming a nightmare that threatens the quality of urban life.

The last few decades have seen a rapid escalation in the number of motor vehicles in developing countries, as a result of various factors, such as the increase in the purchasing power of the middle-income socioeconomic classes, the greater availability of credit, the relative reduction in prices and the greater supply of used vehicles. The growing availability of automobiles has allowed greater individual mobility, which, together with population growth in cities, the smaller number of persons per household and the fact that structured urban transport policies have been applied in only a few cases, has led to an increase in congestion. Although the greater individual mobility provided by the motor vehicle may be considered positive, it also implies more intensive use of the space available for circulation.

The most obvious consequence of congestion is the increase in travel time, especially at peak periods, which has reached levels well above those considered acceptable in some cities. In addition, the slow pace of circulation is a source of exasperation and triggers aggressive behaviour in drivers.

Another result is the exacerbation of environmental pollution. Its relationship with congestion is an aspect that still needs to be studied in greater depth, although valuable evidence has already been obtained in some Latin American cities. Pollution affects the health of all citizens, so that it must be

kept below certain limits. Quite apart from the harm caused by pollution at the local level, however, vehicles also emit greenhouse gases, which adds a global dimension to the issue that cannot be overlooked.

In addition to the above considerations, there are other important harmful effects which should be taken into account, such as the larger number of accidents, the increase in the consumption of fuel for the distance covered and, in general, the higher operating costs of vehicles. The situation is compounded by the fact that congestion affects not only motorists but also users of public transport, who, in developing countries, are lower-income persons; in addition to lengthening their travel time, there is a possibly even more regrettable consequence for them, which is that congestion pushes up fares, as explained in chapter II.

Nevertheless, a limited degree of congestion may not be altogether unacceptable. It is preferable to tolerate a certain level than to adopt measures which have an even greater cost. After all, congestion is a sign of activity, and trying to eliminate it altogether could entail disproportionate investments in the road network which could significantly prejudice various other kinds of socially beneficial ventures.

While it is clear that acute congestion has direct negative consequences, it also has other more general and disturbing effects that loom over cities suffering from it.

## **2. Damage to competitiveness**

Congestion interferes with a city's economic efficiency, since it imposes extra costs that make all activities more expensive and put a damper on development.

In a globalized world like today's, where customers are more and more demanding and there are many places offering advantages for investors, cities have to be competitive both nationally and internationally. For this, they must pay attention to, and reduce, various types of costs, including those that are related to transport, such as the time spent travelling, the energy consumed, the level of air pollution and the number of accidents. Who would start a venture in a city where travel times are intolerable or where there is doubt whether one can arrive on time for one's daily engagements?

Since there are multiple options worldwide to choose from, a city with serious problems of congestion will drive away investors, however favourable other important conditions may be, such as proximity to the high seats of power or decision-making or the availability of a skilled labour force.

Although traffic congestion may not be the only cause, it can be a major factor in the exodus of various activities from traditional city centres in search of conditions that permit better performance. There is a real danger that the centre may remain only as the location of government institutions, small businesses and low-income residents, or it may even be partly abandoned, all of which will result in visible deterioration. Historic centers –especially those



of capital cities– harbour a rich heritage which deserves not only to be preserved but also to remain current and in regular use.

In the medium and long term, congestion can make a city's lifestyle unsustainable. Excessive travel times, fuel consumption and pollution can cancel out the synergy arising from the concentration of services and opportunities offered by cities. In a situation marked by increasing difficulties and danger to public health, more and more people will opt to escape from such an environment and migrate somewhere else.

In short, congestion and its consequences are gradually becoming an acute threat to the sustainability of cities.

### **3. Cities for living, developing and moving about**

There is yet another important consideration, however.

The significant advantages offered by cities have caused them to grow and absorb an inflow of people from rural areas. Today, however, the benefits offered by the concentration of activities are not enough in themselves: cities must also provide a quality of life in keeping with the intrinsic dignity of human beings.

Currently, quality of life is recognized as a fundamental value which, moreover, must be sustained over time. In other words, conditions must be generated to make living more pleasant, and this must be on a lasting basis.

Competitiveness and mobility are part of the quality of life, insofar as they provide fuller opportunities for development, work and recreation. Such conditions favour the possibility of undertaking ventures, working, moving about and relaxing, all of which are considered necessary for better personal fulfilment.

Nevertheless, promoting competitiveness and mobility indiscriminately can, in certain circumstances, detract from the quality of life. Thus, for example, a generous broadening of the roadway for the circulation of vehicles can confine pedestrians into notably insufficient spaces, swallow up large extensions of green spaces, or result in the segregation of zones or neighbourhoods. On the contrary, enough public space must be reserved for walking, jogging or simply getting together with other people, since this is an inherent part of the pleasure of living and also has an important effect in terms of promoting better health for today's sedentary citizens.

Consequently, it is necessary to develop a clear concept of the kind of city which is desired, where there is a harmonious blend of economic efficiency, mobility, a tolerable degree of congestion, a clean environment and a better quality of life, all on a sustainable basis.

Clearly, uncontrolled traffic congestion goes against such aspirations and can give rise to a disturbing future. Thus, it must be controlled in the short and medium term through the application of technical knowledge, as well as by learning to take useful and sustainable measures which must go hand in

hand with new civic attitudes with respect to mobility, the transport system, public spaces and traffic.

At the same time, however, congestion is not a problem to be addressed only in a technical and autonomous way: it must also form part of the broader effort to develop cities for the benefit of people. In designing concrete measures, account must also be taken of their various impacts on harmonious urban development and care must be taken to prevent negative effects. This calls for an integral approach which will enable us to attain cities that offer a better quality of life and are sustainable over time.

## Chapter II

### THE CAUSES AND COSTS OF CONGESTION

#### A. WHAT IS CONGESTION?

##### 1. Popular usage and dictionary definition

The word “congestion” is frequently employed in the road traffic context, both by technicians and by the public at large. Webster’s Third New International Dictionary defines it as “a condition of overcrowding or overburdening”, while “to congest” means “to overcrowd, overburden or fill to excess so as to obstruct or hinder” something; in this case, road traffic.

In order to control a phenomenon, we must first of all understand it. What is congestion, then?

It is usually understood as meaning a situation in which there are a large number of vehicles circulating, all of which are moving forward in a slow and irregular manner. These definitions are of a subjective nature, however, and are not sufficiently precise.

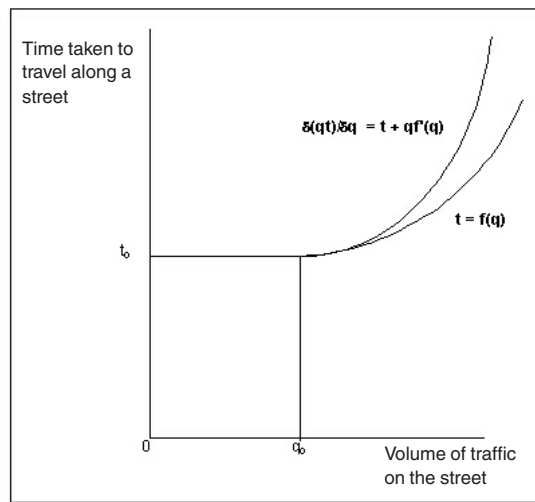
##### 2. A technical explanation

The fundamental cause of congestion is the friction or mutual interference between vehicles in the traffic flow. Up to a certain level of traffic, vehicles can circulate at a relatively freely determined speed which depends on the legal speed limit, the frequency of intersections, and other conditioning factors. At higher levels of traffic, however, every additional vehicle interferes with the circulation of the others: in other words, the phenomenon of congestion appears. A possible objective definition, then, would be: “congestion is the situation where the introduction of an additional vehicle into a traffic flow increases the journey times of the others” (Thomson and Bull, 2001).

At what point does congestion begin?

As traffic increases, traffic speeds go down more and more sharply. In figure II.1, the function  $t = f(q)$  represents the time ( $t$ ) needed to travel along a street at different levels of traffic ( $q$ ). The other curve,  $d(qt)/dq = t + qf'(q)$  is derived from that function. The difference between the two curves represents, for any volume of traffic ( $q$ ), the increase in the journey times of the other vehicles which are in circulation due to the introduction of an additional vehicle.

Figure II.1  
**SCHEMATIC REPRESENTATION OF THE CONCEPT  
OF TRAFFIC CONGESTION**



**Source:** Prepared by the author on the basis of economic theory (supply curve).

It may be noted that the two curves coincide up to a traffic level  $Oq_0$ ; up to that point, the change in the total journey times of all the vehicles is simply the time taken by the additional vehicle, since the others can continue circulating at the same speed as before. From that point on, however, the two functions diverge, and  $d(qt)/dq$  is above  $t$ . This means that each additional vehicle not only experiences its own delay but also increases the delay of all the other vehicles which are already circulating. Consequently, the individual user is only aware of part of the congestion he causes, while the rest is suffered by the other vehicles in the traffic flow at that moment (Ortúzar, 1994). In the corresponding specialized language, users are said to perceive the mean private costs, but not the marginal social costs.

Strictly speaking, users do not have a very clear idea of the mean private costs either, since, for example, few drivers have a clear idea of how much it costs them to make an additional journey in terms of maintenance, tyre wear, etc. In contrast, they do clearly perceive the costs imposed on them by the

government –particularly the fuel tax– which are seen as mere transfers from motorists to the State, all of which distorts their manner to taking decisions.

Another conclusion which can be drawn –and which can be confirmed by simple observation– is that at low levels of congestion an increase in the traffic flow does not significantly increase journey times, but at higher levels the same increase causes considerably greater overall delays.

According to the definition given earlier, congestion begins with a traffic level  $Oq_0$ . Generally, however, this occurs at relatively low traffic levels, unlike what most people think.

### 3. Towards a practical definition in the case of road traffic

Even some specialized studies do not give very strict definitions of congestion. Thus, two well-known specialists in transport modeling consider that congestion occurs when the demand nears the capacity of the travel infrastructure and transit times rise to a much higher level than that obtaining in conditions of low demand (Ortúzar and Willumsen, 1994). Although this definition reflects the perceptions of the average citizen, it does not propose exact limits for the point at which the phenomenon begins.

Is there an objective definition of congestion?

An attempt to define the term precisely in line with the usual perception of it was that made in a draft law like that approved by the Chilean Chamber of Deputies for the introduction of road use tariffs. As the aim was to avoid the possibility of discretionality on the part of public authorities, the definition was very precise. A road was considered to be congested when, in more than half of its total length (including not necessarily continuous stretches), the average speed of the traffic flow was less than 40% of the speed in unrestricted conditions. This state of affairs must be registered for at least four hours a day between Tuesday and Thursday, on the basis of measurements made for four consecutive weeks between March and December. An exact definition was also given of congested areas.<sup>1</sup> This definition was perhaps too precise and difficult to apply in practice, although so far it has not been necessary to apply it, since the draft law has not yet received full legislative approval.

Without going into such detail, yet continuing to seek objectivity, the term congestion could be defined as “the situation which occurs if the introduction of a vehicle into a traffic flow increases the travel times of the other vehicles by more than  $x\%$ ”. An objective although still somewhat arbitrary definition of congestion would be to define it as the volume of traffic at which  $d(qt)/dq = at$ , where  $a$  equals, for example, 1.50. In other words, congestion would begin when the increase in the journey time of all the vehicles already present in the flow was equal to half of the travel time of an additional vehicle.

<sup>1</sup> This Chilean draft law provides for the payment of a fee for the use of urban roads subject to traffic congestion.

## **B. THE CAUSES OF CONGESTION**

### **1. Characteristics of urban transport which cause congestion**

The transport system, including the provision of urban land for transport infrastructure, operates with very special characteristics, including in particular the following:

Why are big cities prone to congestion?

- The demand for transport is “derived”: in other words, journeys are rarely made because of an intrinsic desire to travel but are generally due to the need to travel to the places where various kinds of activities are carried on, such as work, shopping, studies, recreation, relaxation, etc., all of which take place in different locations.
- The demand for transport is eminently variable and has very marked peak periods in which a large number of journeys are concentrated because of the desire to make the best use of the hours of the day to carry on the various types of activities and have an opportunity to make contact with other persons.
- Transport takes place in limited road spaces, which are fixed and invariable in the short term; as will readily be understood, it is not possible to store up unused road capacity for later use at times of greater demand.
- The forms of transport which have the most desirable characteristics – security, comfort, reliability, and autonomy, as in the case of private cars – are those which use the most road space per passenger, as will be explained below.
- Especially in urban areas, the provision of road infrastructure to satisfy rush hour demand is extremely costly.
- Because of the above factors, congestion occurs at various points, with all its negative consequences of pollution, heavy expenditure of private and social resources, and adverse effects on the quality of life.

A further aggravating factor is that, as noted in the previous section, the cost of congestion is not fully perceived by the users who help to generate it. Every time this happens, more of the good or service in question is consumed than is desirable for society as a whole. As users are not aware of the greater costs in terms of time and operation that they cause to others, their decisions on routes, forms of transport, points of origin and destination and time of execution of journeys are not taken on the basis of the social costs involved, but their own personal costs or, rather, an often partial perception of those costs. The natural result is the over-exploitation of the existing road system, at least in certain areas and at certain times.



## 2. The problem is mainly caused by private car users

Some vehicles cause more congestion than others. In transport engineering, each type of vehicle is assigned a passenger car equivalence called a pcu, or passenger car unit. A private car is equivalent to 1 pcu, while other vehicles have equivalencies corresponding to their disturbing influence on the traffic flow or the space they occupy in it, as compared with a private car. A bus is normally considered to be equivalent to 3 pcus and a truck to 2 pcus. Strictly speaking, however, the pcu factor varies according to whether the vehicle in question is close to an intersection or is in a stretch of road between two intersections.

Why do private cars cause more congestion?

Although a bus causes more congestion than a private car, it generally carries more persons. Thus, if a bus carries 50 passengers but a private car only carries an average of 1.5 persons, then every private car passenger is causing 11 times as much congestion as a bus passenger. Consequently, other things being equal, congestion is reduced if the share of buses in the intermodal journey mix is increased. Unless buses transport less than 4.5 passengers, on average they cause less congestion than private cars. It is not normal for buses to transport fewer than 4.5 passengers, although this can sometimes happen, as for example in some sectors of Santiago, Chile, at off-peak hours in the late 1980s, or in Lima ten years later.

The existence of an excessive number of public transport vehicles can help to increase congestion, as noted in a number of cities. One of the features of the current economic models is deregulation, and in the case of urban passenger transport, broad deregulation is normally reflected in an exaggerated increase in the number of buses and taxis and a deterioration in the levels of order and discipline associated with their operation. This phenomenon bore much of the blame for the deterioration in congestion in Santiago in the 1980s and in Lima in the following decade.

The liberalization of the rules on the importation of used vehicles and the deregulation of public transport both had particularly serious effects in Lima. In Santiago, which had some 4,300,000 inhabitants in the late 1980s, there were relatively few cases of the importation of used vehicles, and the public transport fleet (all types of buses, plus collective taxis) did not amount to more than 16,000 vehicles. In the mid-1990s in Lima, however, which had some 6,700,000 inhabitants at that time, the public transport fleet amounted to at least 38,000 vehicles (and some sources indicate that the real number was close to 50,000). In other words, in the mid-1990s the number of units per inhabitant in Lima was between 52% and 101% higher than it had been in Santiago some seven years before, at a time when deregulation in Chile was having its most striking results.

### **3. The state of the roads and driving habits also contribute to congestion**

#### **(a) Urban road networks: design and maintenance problems**

Faulty design or maintenance of road systems causes unnecessary congestion. In many cities there are frequent cases of failure to mark traffic lanes, unexpected changes in the number of lanes, bus stops located precisely where the road width becomes narrower, and other shortcomings which disturb a smooth traffic flow. Likewise, road surfaces in bad condition, and especially the presence of potholes, give rise to increasing constraints on road capacity and increase congestion. In many Latin American cities, such as Caracas, the accumulation of rainwater on roads reduces their traffic capacity and hence increases congestion.

Are there other factors that aggravate the situation?

#### **(b) Some driving habits cause more congestion than others**

There are drivers who show little respect for other road users. In some cities, such as Lima, many drivers try to cut a few seconds off their journey times by forcing their way into intersections and blocking the passage of other motorists, thus causing economic losses to others which are much greater than their own gains. In other cities, such as Santiago, it is a tradition for buses to stop immediately before an intersection, thereby causing congestion (and accidents). In those same cities, as in others that have an excessive number of taxis that do not habitually operate from fixed taxi ranks, these vehicles crawl along looking for passengers, and this also gives rise to congestion.

In addition to these practices, the traffic flows also often include old and poorly maintained vehicles, as well as some drawn by animals. It must be borne in mind that when the traffic flow resumes after being stopped at a traffic light, a form of congestion ensues because vehicles with a normal rate of acceleration are held up by slower vehicles located in front of them. Furthermore, a vehicle which is stopped or moving sluggishly seriously affects the smooth flow of traffic, since in effect it blocks a traffic lane.

Illustration II.1  
**THE SELFISH AND UNDISCIPLINED BEHAVIOUR OF LIMA  
MOTORISTS REDUCES THE CAPACITY OF THE ROAD  
SYSTEM TO A FRACTION OF ITS REAL POTENTIAL**



**Source:** Photograph by Ian Thomson.

**(c) Insufficient information is available on traffic conditions**

Another factor which increases congestion is ignorance of the prevailing traffic conditions. If a motorist with two possible routes, A and B, for reaching his destination knew that traffic conditions were bad on route A, he could use route B, where his own contribution to congestion would be less. A study of a hypothetical city made in the University of Texas in the United States indicates that the fact of being well informed about traffic conditions in different parts of the road network can reduce congestion much more than such drastic measures as levying charges for using congested streets (IMT, 2000). Basic unfamiliarity with the road system can also increase the average distance of each journey and thereby contribute to congestion.

**(d) The result is that there is a generalized reduction in capacity**

Generally speaking, both the way motorists drive and the state of the road and vehicles mean that in Latin America a street or urban road network will assuredly have a lower capacity than one of similar dimensions located in Europe or North America. Measurements made in Caracas in the early 1970s showed that an expressway there had only 67% of the capacity of a United States expressway of similar size.<sup>2</sup> The actual percentage difference may vary from one city to another, but there is no doubt that the road systems of Latin American cities are relatively prone to congestion.

<sup>2</sup> Figures calculated on the basis of data from Vorhees (1973) and Winfrey (1969).

#### 4. There is also an institutional problem

In almost all Latin American cities, the deterioration in traffic conditions has been significantly worse than it could and should have been, partly because of inappropriate actions by the corresponding authorities. It is obvious that the problem has clearly overtaken the institutional capacity to deal with the situation.

How have the authorities tackled the problem?

So far, the reaction of the authorities has only been of a piecemeal nature, because in virtually the whole region the responsibility for urban transport planning and management is split up among a host of bodies, including various national ministries, regional governments, municipalities, suburban train or metro companies, the traffic police, etc. Each of these does what it considers to be most appropriate, without taking much account of the repercussions on the interests of the other institutions.

A municipality, for example, fearing the diversion of economic activity to another part of the city, may authorize the construction of multi-storey car parks, or allow parking on the streets, without bothering about the impact of the congestion thus generated on road users who have to cross through the area in question.

Another situation which reflects the consequences of decisions taken without coordination and without considering their broader repercussions may occur in the context of a mass transit system such as the metro. Because of the greater accessibility provided, land use becomes more dense and office blocks are built, and as municipal regulations usually demand a certain minimum number of private parking spaces for such buildings, this encourages the staff to come to work in their cars. Thus, this set of measures fosters increased congestion.

Furthermore, in such a sensitive area as urban transport, strong pressures are exerted by organized groups, such as transport interests, as well as by politicians, who put forward their own points of view and sometimes take up arms on behalf of particular interests, which complicates the situation still further.

All the above factors are a source of distortions, yet urban transport should be handled in an integral, technical manner, instead of measures being taken separately by each institution or in favour of sectoral interests.

### C. THE INVASION OF THE PRIVATE CAR

The last decade of the twentieth century brought with it a big increase in the number of private cars circulating in Latin America, as well as in their use for the most varied purposes, including journeys to places of work or study, thus exerting heavy pressure on the road network. What are the causes of these phenomena?

## 1. Economic reforms have made private cars more easily accessible

Among other effects, the economic reforms adopted in the region in the 1990s brought with them higher economic growth rates and lower car prices.

How have the economic reforms affected the possibility of acquiring a private car?

Instead of the almost always negative per capita GDP growth rates of the 1980s, the 1990s brought relatively high positive growth rates. Thus, for example, Uruguay went from an average annual growth rate of -1% between 1981 and 1988 to a rate of +4% between 1991 and 1994 (ECLAC, 1989 and 1995a). This had a favourable repercussion on personal income levels, thus making more resources available for the acquisition of consumer durables.

At the same time, in many cases there was a reduction in the tax burden on automobiles, especially in customs duties. Moreover, in some countries there was an appreciation in the exchange rate, thus making imported products cheaper to buy. In Colombia, for example, the real exchange rate in 1994 was only equivalent to 75% of that prevailing in 1990 (IDB, 1995).

This tendency does not necessarily mean that actual prices are lower, because at the same time the quality of vehicles has improved. In the case of those vehicles whose characteristics have remained relatively unchanged, however, there has been a real reduction in their purchase prices. In the Chilean market, for example, in 1996 a Volkswagen Beetle cost the equivalent of US\$ 7,780, whereas in 1982 it had cost the equivalent of US\$ 8,902 at 1996 prices.

The real reduction in the prices of used cars has undoubtedly been even greater, although it is difficult to obtain reliable data in this respect. The rate of depreciation of private cars is directly related with the rate of ownership. In countries where there are few vehicles per person, a second-hand car is a relatively scarce good, and the price at which it is sold will reflect a limited supply and, sometimes, abundant demand. The rise in rates of vehicle ownership in Latin America in recent years has reduced the relative scarcity of used cars, thus tending to increase supply and reduce demand, because a larger proportion of the population now already have one, and hence drive down prices, putting such vehicles within the reach of lower-income families.

Consequently, in the current Latin American situation real incomes are rising and automobile prices are tending to go down.

## 2. The popularization of private car ownership

In Latin American cities, the evolution of residents' incomes and car prices –especially those of used cars– means that ownership of a vehicle is ceasing to be an unattainable dream and is becoming an accomplished fact for many families. The increase in the rate of car ownership is a

What has happened with the number of cars?

phenomenon which is repeated almost everywhere in Latin America and has made it possible –especially for the middle class– to reap one of the most important fruits of technological progress in the twentieth century.

In the countries where economic reforms were implemented rapidly, automobile imports increased equally fast (see table II.1).

Table II.1  
**ECUADOR AND PERU: IMPORTS OF PASSENGER VEHICLES <sup>a</sup>**  
(Thousands of dollars)

Year	Ecuador <sup>b</sup>	Peru
1989	10 062	6 482
1990	23 432	11 880
1991	23 554	170 668
1992	166 109	213 018
1993	245 895	165 647
1994	374 038	252 421

**Source:** ECLAC, on the basis of official data.

<sup>a</sup> Figures exclude buses.

<sup>b</sup> Figures refer specifically to private transport vehicles, within the general heading of consumer durables.

The column corresponding to Peru shows that between 1990 and 1991 the value of automobile imports increased by a factor of 14. Peru freed not only the importation of new vehicles but also that of used ones (except for a brief period between February and November 1996). Consequently, the average unit cost went down, indicating that the number of units imported must have increased even more than the total value of imports.

In some countries that manufacture motor vehicles themselves, the economic reforms resulted in an increase both in vehicle imports and in domestic production. This was so in Brazil, where automobile imports had been subject to heavy duties, as part of a policy designed to promote domestic production of these goods. Thus, between 1990 and 1994 imports grew by over 10,000%, albeit starting from a very low level, yet domestic automobile production also rose, by 70%. Vehicle exports were reduced because manufacturers preferred to sell their output on the growing domestic market (see table II.2). Another factor which influenced the situation, during a period from mid-1994 on, was the appreciation of the local currency. A concrete result was that in São Paulo, between 1990 and 1996 the population grew by 3.4% but the vehicle fleet expanded by 36.5%.



Table II.2  
BRAZIL: APPARENT CONSUMPTION OF AUTOMOBILES<sup>a</sup>

Year	Units		Apparent consumption of automobiles <sup>a</sup>
	Imported	Produced	
1990	1 310	602 545	483 084
1991	11 146	615 097	499 090
1992	30 714	667 229	454 817
1993	70 438	929 582	750 413
1994	138 679	1 026 827	890 691
1995	320 261	1 147 897	1 278 437

**Source:** Economic Commission for Latin America and the Caribbean (ECLAC), "El tránsito urbano en la era de la apertura económica", *Boletín FAL*, No. 132, Santiago, Chile, March-April (<http://www.eclac.cl/transporte>), 1997.

<sup>a</sup> Production plus imports, less exports.

On the basis of data corresponding to the 34 municipalities in Greater Santiago, the following equation was developed to determine the number of automobiles per family:

$$y = e^{(0.2850 - 134.5746/x)}$$

where y = number of automobiles per family  
x = monthly income per family in 1990 pesos.

This equation has the expected form, although it could perhaps be subject to some technical reservations.<sup>3</sup> By using it, it is possible to estimate the elasticity or unit variation in the rate of automobile ownership with respect to income level. Table II.3 shows that this elasticity is inversely related to income level. Although the elasticity in low-income communes (La Pintana) is very high, a 1% increase in income only gives rise to a small increase in the absolute number of automobiles per family. In contrast, a 1% increase in income in a middle-income commune results in an increase in the absolute number of automobiles per family which is very similar to that registered for a very high-income commune.

<sup>3</sup> The equation was adjusted ( $r = 0.9586$ ) on the basis of data collected at the municipality level in a cross-sectional transport survey carried out in 1991. The changes estimated by the equation in the rate of automobile ownership are only as a function of changes in family income: they do not incorporate the influence of changes in the prices or quality of automobiles, since these factors remain constant in a cross-sectional analysis. In fact, prices have tended to go down and vehicle quality has gone up, so that the changes in rates of ownership over the years in question are actually greater than those calculated by the equation.

Table II.3  
**SANTIAGO, CHILE (THREE MUNICIPALITIES): ESTIMATED RELATION  
 BETWEEN INCREASE IN AUTOMOBILE OWNERSHIP PER FAMILY  
 AND INCREASE IN AVERAGE INCOME**

Municipality	Monthly family income	Automobiles per family	Elasticity of rate of automobile ownership per family with respect to family income	Increase in number of automobiles per family for a 1% increase in family income
Vitacura	589 700	1.71	0.23	0.0039
Santiago (centre)	126 700	0.311	1.06	0.0033
La Pintana	39 730	0.051	3.39	0.0018

**Source:** J. Kain and Z. Liu, *Efficiency and Locational Consequences of Government Transport Policies and Spending in Chile*, Harvard, Harvard Project on Urban and Regional Development in Chile, 1994, table A.7.

The most important conclusion to be drawn from this analysis is that an increase in income results in significant expansion of automobile ownership, not only in the richest neighbourhoods but also in middle-income areas. Thus the total number of automobiles in Santiago grew at the rate of 8% per year during the 1990s.

### 3. Where there are fewer cars it nevertheless seems harder to get about

The growing number of vehicles undoubtedly favours increased congestion, but at all events the rates of automobile ownership in Latin American cities are still much lower than in developed countries. In 1980, the number of automobiles per person in North American cities such as Houston, Los Angeles, Phoenix, San Francisco, Detroit, Dallas, Denver, Toronto and Washington was between 0.55 and 0.85, while in European cities such as Brussels, Amsterdam, Copenhagen, Frankfurt, Hamburg, London, Stuttgart and Paris it was between 0.23 and 0.43. Ten or fifteen years later, some Latin American cities (such as Chiclayo or Huancayo in Peru) still had no more than 0.02 cars per inhabitant, and in Lima, even though the boom in vehicle imports had already begun, there were still no more than 0.05 cars per person, while in Santiago there were 0.09. On the other hand, in a few Latin American cities the rate of ownership was already nearing the lower limit of Western European cities. In Curitiba, for example, in 1995 there were already close to 0.29 cars per person.

Is it only the number of vehicles that favours congestion?

Nevertheless, there is evidence that it is easier to move about in the big cities of the developed world than in the comparable cities of Latin America. In Quito, whose population in 1990 was approximately one million, the average journey time between home and workplace was 56 minutes, whereas in Munich, which had approximately 1.3 million inhabitants, the corresponding time was only 25 minutes. Likewise, in Bogotá (5 million inhabitants) the journey time was 90 minutes, while in London (6.8 million) it was 30 minutes. Many other examples along the same lines could be quoted. Clearly, in the cities of the developed world there is a greater capacity to live with the automobile while avoiding its worst consequences, but Latin America has not yet learned to do this.

Furthermore, it would appear to be easier to move about in the Latin American cities with the highest rates of car ownership than in many where the rates are lower. Curitiba, for example, has more cars per person than Guatemala City, which is of similar size, but travelling in the first-named city, whether by car or in public transport, is a good deal less disagreeable than in the Central American city.

The explanation for these apparent contradictions is to be found in the marked propensity to make intensive use of private cars for all kinds of purposes.

#### **4. The strong influence of subjective factors**

One feature which aggravates congestion in Latin America is the marked preference of the population to use private cars. A clear example was Mexico City, which has suffered for years from acute problems of congestion. In order to reduce environmental pollution, it was decided to prohibit the use of one-fifth of the existing vehicles from Monday through Friday, but even this drastic measure did not succeed in persuading those affected to use public transport, even though there was an extensive metro system. Instead, the widespread response was to acquire additional vehicles to evade the effects of the measure, since many people preferred to suffer the effects of congestion rather than use public transport.

In such circumstances, even if the authorities responsible for Latin American urban transport had clear ideas about how to control traffic in the cities (which is unfortunately often not the case), it would be difficult to put them into practice because members of parliament and city councillors, worried about losing votes among the increasingly numerous group of private car owners, would not approve them.

The inhabitants of the cities of the developed world are less likely to use their cars to go to the office in the morning rush hour. A clear distinction is drawn between owning a car, and using it in situations that give rise to major difficulties. A New York or London banker living in the suburbs would never dream of travelling every day to Wall Street or the City in his private car,

because in both cases there is a good-quality public transport system. In contrast, his opposite number in São Paulo or Santiago would never dream of travelling to the city centre any other way. It is likely, however, that in the future there will be a change of attitude among motorists, and indeed, in some cities with a notably higher level of culture –such as Buenos Aires, where the quality of public transport is also higher than in most Latin American cities– there is already some evidence of a greater willingness to use public transport than in some other cities of the region.

What is the reason or explanation why there is such a strong preference for using private cars? One important aspect in this connection is that of status.

Why do people prefer to use private cars?

In Latin America, the automobile is still considered not only a means of transport, but also an indication of its owner's status in society. A person driving a BMW will be considered as superior to one driving a Suzuki, while a person who arrives at the office by car rather than bus is seen as someone who has moved up in the world. The prestige attached to being a car owner is a strong factor in the volume of traffic.

In addition to these reasons related with the social structure and cultural characteristics, the following considerations are also important in the region:

- The poor quality of the buses compared with the aspirations of car owners
- The fact that the buses are very crowded at rush hours
- The feeling of insecurity caused by the dangerous way some bus drivers operate their vehicles<sup>4</sup>
- The real or assumed possibility of being a victim of delinquents on board public transport vehicles.

The preference for travelling by private car becomes a problem at rush hours, when there is a concentration of journeys for reasons of work or study. Not even serious delays in journeys are enough to cause people to stop using their cars. If they had to choose between reaching their destination slowly by private car on congested roads and arriving a little more quickly by public transport, it is by no means certain that many Latin American motorists would opt for the latter alternative.

The strong preference for the private car therefore has a number of consequences, such as the following:

- The number of motorists willing to move to new public transport systems of no more than regular quality may be quite small, so that the great majority of users of a new metro line would come from former bus users rather than private motorists

<sup>4</sup> A telephone survey made in Santiago, Chile in March 2001 revealed that 63% of public transport users considered that travelling on it was unsafe in terms of traffic accidents, while 70% considered that bus drivers drove irresponsibly (survey published in the electronic newspaper *El Mostrador*, 12 April 2001)(<http://www.elmostrador.cl>).

- In order to interest private motorists in public transport it would be necessary to offer them a better-class option, not only in terms of objective quality (fares, journey times and frequency of service) but also in terms of its subjective features (air conditioning, reclining seats, etc.)
- Even if high taxes are imposed on fuel, road use or parking, this would only cause a few people to change to public transport. Thus, i) these measures would serve rather to collect money that could be used to change the habits of the travelling public, and ii) while raising these levels of taxation would produce considerable fiscal income, it would bring relatively few social benefits

The preference for travelling by private car can also have other consequences which go beyond the limits of the transport sector proper and have negative macroeconomic implications. Consider, for example, the rises in international oil prices in 1999 and 2000. The typical Latin American motorist probably did not reduce his vehicle use much but instead restricted his consumption of other goods and services –many of them produced domestically– thereby reducing the demand for them in the short term. At the same time, importing countries had to increase the amount of foreign exchange spent on fuels because of their higher prices and the fact that demand for them is inelastic or at least not very sensitive to price variations.

Having a car to go to a shopping centre, visit friends or relations in distant parts of town, or travel outside the city is one of the fruits of economic development, and its costs are generally internalized to a large extent by car owners, since these journeys are made at times of low congestion. Using the car every day to go to the office or the city centre generates high external costs in terms of congestion and pollution and does considerable harm to society, however. Securing a better balance between the ownership and use of private cars is therefore one of the main challenges to be faced today in the Latin American transport sector.

## **D. HOW SERIOUS IS THE PROBLEM, AND WHO SUFFERS ITS EFFECTS?**

### **1. Various indicators point to a serious and worsening situation**

Taken as a whole, urban transport is a major activity in national life. The operation of the vehicles circulating on the roads of cities with more than 100,000 inhabitants absorbs around 3.5% of the GDP of Latin America and the Caribbean, to say nothing of non-essential journeys such as weekend trips. The social value of the time taken up by journeys is equivalent to about a further 3% of GDP (Thomson, 2000b). It can be seen from these figures that resources involved in urban transport are very significant.

These percentages are very probably on the increase, for various reasons. One is the increase in the rate of vehicle ownership and the tendency towards intensive use of automobiles, as already mentioned. Another is the expansion of the cities and the consequently longer journeys needed (Thomson, 2002a).

The growing demand for use of a relatively constant road supply inevitably leads to a progressive decline in traffic speeds. This situation is deteriorating at an increasingly rapid rate, as shown by the form of the statically determined equations relating traffic speed on a street with the traffic volume.

At rush hours, a large part of the road network in Latin American cities is operating very close to its maximum capacity, which

How serious is the problem?

means that even small increases in traffic flows very severely aggravate congestion. Although there are not many data directly reflecting the trend in terms of congestion over the years, data for São Paulo indicate that in 1992, on average, some 28 kilometres of the main road network suffered from acute congestion in the morning and 39 kilometres in the evening, but by 1996 the number of kilometres had risen to 80 and 122, respectively (Companhia de Engenharia de Tráfego, 1998).

The case of Santiago, Chile, is interesting because this city is the capital of the Latin American country where the process of economic reform and greater openness began. There is growing congestion, not only in the richest communes but also in some middle-income ones. Congestion exists not only in the avenues of the highest-income neighbourhoods, located in the northeastern part of the city, and in the roads leading into the city centre, but also in roads in other parts of the city where family incomes are much lower, and which are not even areas of habitual transit for persons with high incomes.

With regard to the cost of the congestion caused, estimates for the conditions prevailing in Caracas in 1971, when the situation was not as serious as it is today, indicate that each occupant of a private car gave rise to a congestion cost of US\$ 0.18 per kilometre, at 2000 prices, while the cost for each bus passenger was US\$ 0.02 per kilometre.<sup>5</sup>

It therefore seems reasonable to conclude that the costs of congestion are high and that, conversely, the adoption of measures of only moderate cost in order to reduce them would bring significant net benefits. Conservative calculations show that increasing the average speed of private car journeys by 1 km/hr and that of public transport by 0.5 km/hr would reduce journey times and operating costs by an amount equivalent to 0.1% of GDP (Thomson, 2000b).

In any case, the mere fact of measuring traffic speeds or calculating the monetary costs of congestion does not reflect the full depth of the problem. For example, there are people who, in order to avoid some of the effects of congestion, change their forms of conduct

Are the consequences of congestion restricted merely to higher costs?

<sup>5</sup> Estimates based on Thomson (1982).

and adopt habits which they would not normally prefer, such as leaving the house very early in order to travel before the times of worst congestion, or living close to their workplace.

There are also other serious consequences that severely affect urban living conditions, including the increased air pollution caused by the higher fuel consumption of vehicles moving at low speed in severely congested traffic conditions, higher noise levels around the main roads and streets, the irritability caused by loss of time, and the increased stress of driving in the midst of an excessively congested mass of vehicles. These other results of congestion may be difficult to quantify, but they nevertheless cannot be ignored, since they are factors that further aggravate an already serious situation.

## 2. Who pays the costs of congestion?

It must be clearly stated, for a start, that the harmful effects of congestion are suffered by all city dwellers, in terms of a deterioration in various aspects of their quality of life, such as greater air and noise pollution, a negative impact on mental health, etc. Therefore, one way or another, no-one is immune to those effects.

Is there anyone who can escape the effects of congestion?

If the analysis is centered on those who have to travel, the effects of congestion can be determined by breaking down its cost into two fundamental components: the time of the persons involved and the operating costs of vehicles, especially fuel. Both of these costs are increased when travelling in conditions of congestion.

There is no question but that motorists themselves suffer the consequences of congestion. In other words, they suffer the effects of the phenomenon for which they themselves are responsible, in terms of longer journey times and higher operating costs.

However, motorists are not the only ones who suffer the effects of congestion, for this also aggravates the already unsatisfactory condition of public transport, whose users are thus also seriously affected, although they are not responsible for causing the problem. This situation is a source of social inequity, since public transport is used mainly by poorer persons, who are thus captive clients.

Is there anyone who can escape the effects of congestion?

### (a) Congestion holds up bus passengers

Congestion obviously causes bus passengers to take longer to complete their journeys. These longer journey times are a loss in real terms, although perhaps this does not attract so much attention because these passengers have relatively low incomes, so that their personal time is assigned a low monetary value.

Especially in Latin America, urban bus users have much lower incomes than those of urban motorists. In Santiago, Chile, analysis of the data from a study of origins and destinations carried out in 1991 enables the family income of bus passengers to be estimated at 99,321 pesos, compared with a family income of 308,078 pesos for private car users. In other words, the income of private car users was over three times that of bus passengers. Data for São Paulo in 1977 show that in principle the situation there was not too different from that of Santiago (see table II.4), and if measurements were available for other cities of the region they would probably give similar conclusions.

Table II.4  
**SÃO PAULO: RELATIVE INCOMES OF USERS OF DIFFERENT  
 MEANS OF TRANSPORT, 1977**  
*(Private cars = 100)*

Means of transport	Relative income of travellers
Bus only	55
Private car only	100
Taxi only	91
Metro only	89
Suburban train only	39
Combination bus+bus	50
Combination bus+metro	62.5
Combination bus+train	50

**Source:** Based on estimates of the Empresa Metropolitana de Transporte Urbano de São Paulo for the year in question.

#### **(b) Congestion causes higher bus fares**

Another factor, which many passengers may consider to be more important than longer journey times, is the level of bus fares. Congestion holds up not only the occupants of buses, but also the buses themselves, so that in order to provide a given transport capacity it is necessary to use more buses, with their respective drivers, consequently resulting in higher fares.

This phenomenon was analysed in 1982 and it was estimated that an increase in the average speed of public transport in Santiago from 15 to 17.5 km/hr at peak hours would make it possible to reduce fares by as much as 5% (Thomson, 1982). A more recent study on the largest cities in Brazil estimated that congestion increased the operating costs of bus transport by up to 16% (see table II.5). It may be noted that the percentage reductions were much lower in the cases of Brasília, where the amount of road space is unusually generous, and Curitiba, where the buses operating the radial routes have exclusive bus lanes.

In the conditions prevailing in the year 2000, after almost 20 years of real increases in the cost of buses and the incomes of their drivers, a reduction in fares of 10% would undoubtedly be feasible.



Table II.5  
**BRAZILIAN CITIES: INCREASE IN OPERATING COSTS  
 OF PUBLIC TRANSPORT DUE TO TRAFFIC CONGESTION**  
 (Percentages)

City	Increase in bus operating costs due to congestion
Belo Horizonte	6.2
Brasília	0.9
Campiñas	6.4
Curitiba	1.6
João Pessoa	3.7
Juiz de Fora	2.1
Recife	3.5
Rio de Janeiro	9.6
São Paulo	15.8

**Source:** Associação Nacional de Transportes Públicos (ANTP), "Estudio de deseconomías del transporte urbano en Brasil: los impactos de la congestión", *Boletín de los transportes públicos de América Latina*, año 5, Nº 30, São Paulo, 1999.

## E. HOW TO TACKLE THE SITUATION

Traffic congestion, especially in the big cities, is an increasingly widespread problem all over the world. The enormous and growing costs caused by it in terms of loss of time and vehicle operation make it essential to find ways and means of tackling it.

### 1. A little congestion does no harm

In urban areas, especially at times of greatest demand, congestion is inevitable and may even be desirable, within certain limits, in that the costs it causes may be less than those needed to eliminate it altogether. Trying to do away with congestion altogether would involve the following costs, among others:

Must congestion be completely eliminated?

- Those connected with the investments needed to expand road capacity, which may exceed the costs caused by moderate levels of congestion
- Those caused as a consequence of the diversion of users to other roads, forms of transport or times of travel
- Those associated with the possible suppression of journeys as a result of the application of restrictions on motorists

Furthermore, under-utilization of the existing road space also represents a loss of benefits for society, and it should not be forgotten, either, that congestion is a result of human activity which, in spite of the congestion caused, represents advantages for those making the journeys in question (Taylor, 2002): naturally, a city with a low level of activity will not suffer from congestion.

It is therefore not a question of trying to eliminate congestion completely, since this is either impossible or very costly, and it may not even be desirable. What is essential is to keep congestion under control, since if it becomes more serious this will adversely affect the sustainability of big cities.

## **2. The authorities should take a new view of the situation**

The deterioration in traffic conditions has been considerably worse than it could and should have been, partly because of the inappropriate measures taken by the responsible authorities. The expansion in the number of private vehicles has clearly exceeded the institutional capacity for dealing with the situation.

How should the authorities tackle the problem?

So far, the authorities have only reacted in a piecemeal manner, because all over Latin America responsibility for the planning and management of urban transport is split up among a host of bodies, including various national ministries, regional governments, municipalities, suburban train or metro companies, the traffic police, etc. Each one of these does what it considers best, without taking much account of the repercussions on the interests of the other institutions.

Thus, for example, because a municipality fears the possible diversion of economic activity to another part of the city, it may authorize the construction of multi-storey car parks, or allow on-street parking, without bothering about the impact of the congestion thus generated on road users crossing through the area in question.

Another situation reflecting the consequences of separate decisions taken without foreseeing their broader repercussions may arise in the context of a mass transit system such as the metro. Because of the greater accessibility created, land use becomes more intensive, office blocks are built, and as municipal regulations usually require a certain minimum number of private parking spaces for such buildings, this encourages the staff to come to work by car. In other words, these measures regarding parking spaces foster an increase in congestion.

Likewise, in an area as sensitive as that of urban transport, strong pressures are exerted by organized groups – road transport firms, for example – as well as by politicians who put forward their points of view and sometimes come out in defence of particular interests. All this leads to distortions and complicates the situation still further.

Institutions must therefore expand the size and quality of their capacity to respond to problems and, even better, address them in advance. It is also necessary to develop the capacity to withstand the pressures experienced from so many different sources.

What is needed, then, is growing professional and specialized competence in transport management, both in the responsible bodies and in universities and national consulting firms. Traffic must also be dealt with in a global manner, and not separately at the level of each individual institution.

### **3. An integral approach is called for**

Congestion is too serious and far-reaching a problem to believe that it can be relieved through unilateral, erratic or voluntaristic measures. On the contrary, keeping it under control and ensuring a minimum of sustainability of urban standards of living calls for a multidisciplinary effort which includes the improvement of driving habits, the provision of better infrastructure, and measures to manage traffic (supply-side management) and rationalize the use of public roads (demand management).

Is there an approach that holds out the hope of being able to accomplish something?

In other words, the problem must be approached in an integral manner and a set of feasible measures must be taken to improve the productivity of the urban transport system, while bearing in mind at all times that the application of a given measure may have repercussions on other aspects of road traffic, and this must be anticipated in order to avoid negative effects.



## Chapter III

### CONTROLLING CONGESTION THROUGH SUPPLY-SIDE ACTIONS

#### A. TRANSPORT SUPPLY AND THE CITY

##### 1. What is transport supply?

Transport supply consists of a combination of means that make transportation possible. They can be classified as follows:

What does transport supply encompass?

- Infrastructure: roads designed for circulation;
- Means of transportation: vehicles; and
- The manner in which both are managed

Urban transport supply tends to be categorized according to its capacity, that is, the number of persons who can be transported in a given period of time. Just from the infrastructure standpoint, capacity is usually measured as the number of vehicles that can circulate in a given area in a certain period of time; this parameter is meaningful when analysing congestion, but it should not be forgotten that what really matters in a city is allowing people to move around satisfactorily..

##### (a) The road infrastructure

The simplest forms of road infrastructure are nodes and arcs. Nodes or intersections are points where two or more roads cross, meaning that the road space is shared by them; at intersections, vehicles can switch routes. Arcs are stretches of motorway between intersections, generally of uniform width; it is not possible for vehicles travelling along an arc to change routes; they are only able to exit or enter the roadway from adjacent properties.

A succession of arcs and intersections make up what is called the road axis, or simply the road or street. Roads cross each other to form a true grid. For this reason, what happens on one street can have repercussions on others, especially in situations of congestion. Hence, in technical language the term “road networks” is used for the combination of arcs and nodes that join together to make up a system. Traffic patterns make this evident, as the impact of one incident spreads throughout a region in a chain reaction. A road network should be treated as such, which often means that the areas of analysis must be expanded so that suitable measures can be adopted to improve transport operations.

#### **(b) Means of transportation**

A wide variety of vehicles use the streets and avenues of a city, ranging from cars to large buses and multi-passenger, service and freight vehicles of all sorts. There numerous types of vehicles transport persons and things, although their forms and quality of service vary. In addition, there are modes of transportation that do not make use of motorways, such as subway systems. An important issue in connection with congestion is the use that each type of vehicle makes of the space available for circulation, and it should be noted that those carrying the most passengers are the most efficient in this regard, even though they may not fare as well in relation to other criteria such as speed of movement or convenience.

#### **(c) Management of the transport system**

The road network and vehicles should be considered as a whole, since the same infrastructure and the same types of vehicles can yield quite different transport capacities. In other words, how the system is managed makes a big difference. Whether the streets have one- or two-way traffic, whether one can turn in any direction at all intersections, whether traffic lights are synchronized, whether average vehicle occupancy is high or low, or whether buses are given priority on the roadway, are all factors that change the outcome. In fact, it is the combination of infrastructure, vehicles and transport management that determines transport capacity or supply.

### **2. Frequent calls to expand transport supply**

In a given situation, a high concentration of activities in urban areas and the intensive use of public space, particularly by transit vehicles, can create an imbalance between the volume of traffic and the capacity of the motorways. The result is vehicle congestion, a deterioration in service for drivers and passengers and a poorer quality of life for the population in general.

As congestion becomes apparent, one option to combat it is to expand the supply of transport. Supply-side measures include actions affecting roads, vehicles and their operation. Improving any component of supply yields benefits in the form of reduced congestion.

The first option considered is usually to enlarge the capacity of the road network with a view to enhancing the flow of traffic. With respect to the infrastructure, the greatest technical efforts have traditionally focused on easing or eliminating congestion, and many of the measures proposed are intended to improve intersections or roadways. Large and costly projects such as expanding or building expensive highways or building under- and overpasses are viewed more favourably than other alternatives, even though they often do not provide a lasting solution. In any event, the idea of making a large number of small improvements, such as upgrading crosswalks or improving signposting, should not be discounted because they can yield great benefits when properly designed.

It is also possible to focus on the size of vehicles or their capacity as away of making more efficient use of road space. Initiatives such as large-capacity buses on heavily trafficked avenues, collective taxis and carpooling are examples of this approach.

The third component of supply is management, which provides countless options that are increasingly broad in scope, thanks to modern technology. Synchronization of traffic signals, bus priority systems, flexible management of the direction of travel and efficient traffic reporting systems have all made valuable contributions, for example.

It is not hard to see that the three components of supply are closely linked to each other. Measures affecting them can and should be complementary in order to enlarge capacity and ease congestion in the short term. The choice of the right packages is the key.

### **3. Cities are for living and moving**

Supply-side measures are designed to improve mobility and possibilities for getting around the city. As important as this is, however, other essential urban values must be safeguarded as well, including habitability and quality of life. Hence the importance of considering the urban impact associated with every measure, since the degree to which changes in the form and use of motor will ways affect adjacent areas depends on the scale of those changes and the type of land use involved.

Some of the most serious consequences of inadequate transport supply management in response to congestion are the loss of space, the lower priority that may be given to pedestrians and the segregation of districts and neighbourhoods. Sidewalks and green spaces have suffered from the physical encroachment of road projects, which may the walking and recreational opportunities for residents, adults and children alike. On other occasions,

virtually impassable barriers have been erected to prevent local access, which definitely translates into a poorer quality of life.

It is not easy to balance mobility and habitability. One way to make these two factors compatible is to designate specialized functions for certain roadways, giving priority to the flow of traffic on main arteries while restoring the neighbourhood atmosphere on streets leading to places where trips are generally started or finished.

All urban motorways that exist today can be placed somewhere along this spectrum. Some routes can be designated for joining distant points of origin and destinations, with little or no intermediate access to properties located along the way, while always providing solutions for interconnectivity between adjacent areas. This type of thoroughfare does not appear to be appropriate for city centres, as it inhibits pedestrians and may generate noise pollution. Other streets should give priority to local access, which may even be accomplished by going so far as to make them inconvenient for going from one part of the city to another. And finally, another category of streets and avenues could lend themselves more to mobility or to access, without excluding other uses.

The city requires broad corridors for rapid mobility as well as quiet streets for the end of the journey in order to safeguard residential activity.

The classification of roadways and the definition of the corresponding design and operational criteria would make it possible to establish an order in which the two prime functions of urban life, habitability and mobility, could remain in balance.

## **B. ACTIONS ON INTERSECTIONS**

Intersections are points where two or more roads cross. Normally, it is intersections that determine the capacity of thoroughfares; because they are a common point between two or more roads, they must allow for the alternation of conflicting flows. Thus, traffic spends less time moving when it reaches an intersection than when it is flowing along an arc or straight line. Consequently, intersections become congested first and indeed become bottlenecks or operational restrictions for the entire system. That is why interventions in intersections have a great potential benefit for traffic flow.

### **1. Types of intersections**

There are numerous forms of intersection, the most frequent of which are listed below (MIDEPLAN, 1988a):

#### **(a) “T” or “Y” intersections**

These consist of three branches. Figures III.1 and III.2 show some examples of this type of intersection, all with islands and traffic channelling.



**(b) Crossroads**

These are made up of four branches coming together in the shape of a cross. Figure III.3 depicts typical examples of this type of intersection.

**(c) Multiple intersections**

These are made up of more than four branches and are the most difficult case to deal with. It is generally preferable to eliminate one of the branches, connecting it to another outside the intersection if possible.

**(d) Roundabouts**

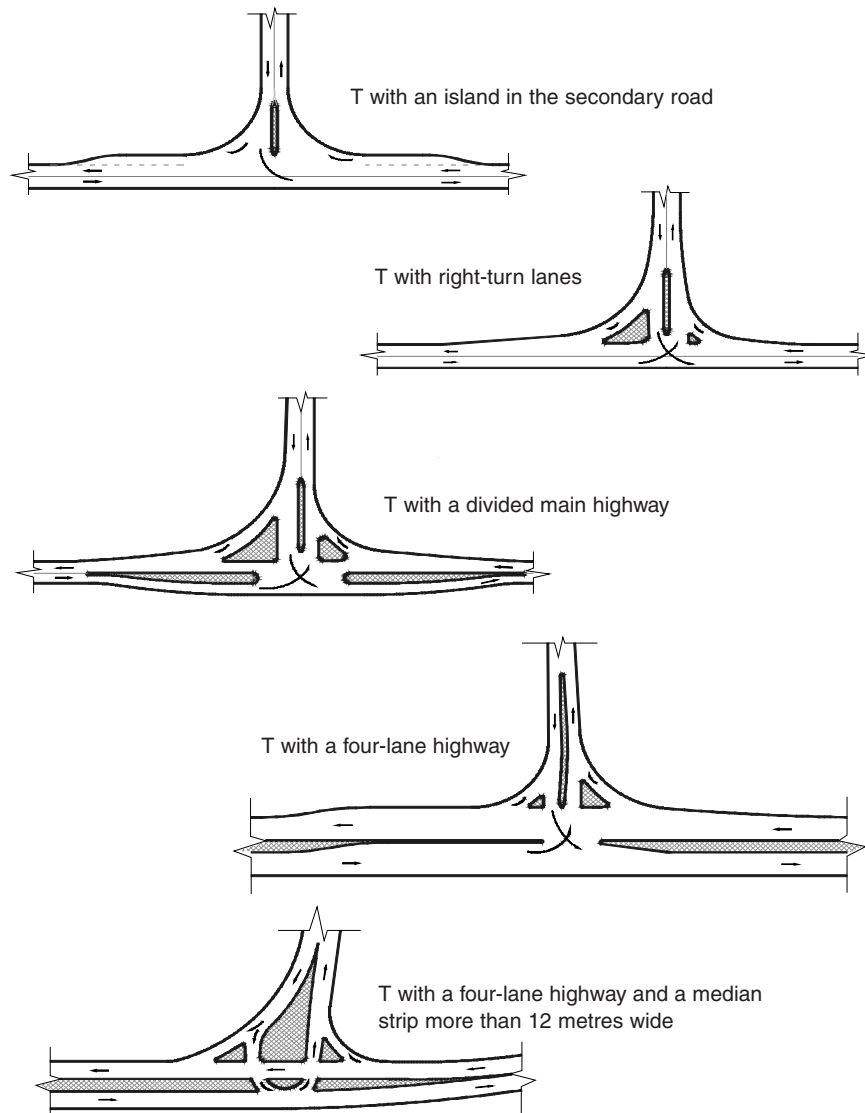
In this solution, branches are joined by means of a circular, elliptical or similar ring around which vehicles travel until they reach the branch where they exit. It may require that incoming and outgoing traffic be weaved together at one or more points (figure III.4). Traffic signals should not be used and incoming vehicles should yield to those already in the ring on the left (MIDEPLAN, 1998a).

One example of this type of solution is the mini-roundabout, characterized by a considerably smaller centre island less than five metres in diameter. Figure III.4 shows a British example, in which a mini-roundabout significantly increases its capacity with a smaller island and multiple access lanes.

The roundabout is a compromise that can offer some advantages if many of the following conditions are also present (MIDEPLAN, 1998a):

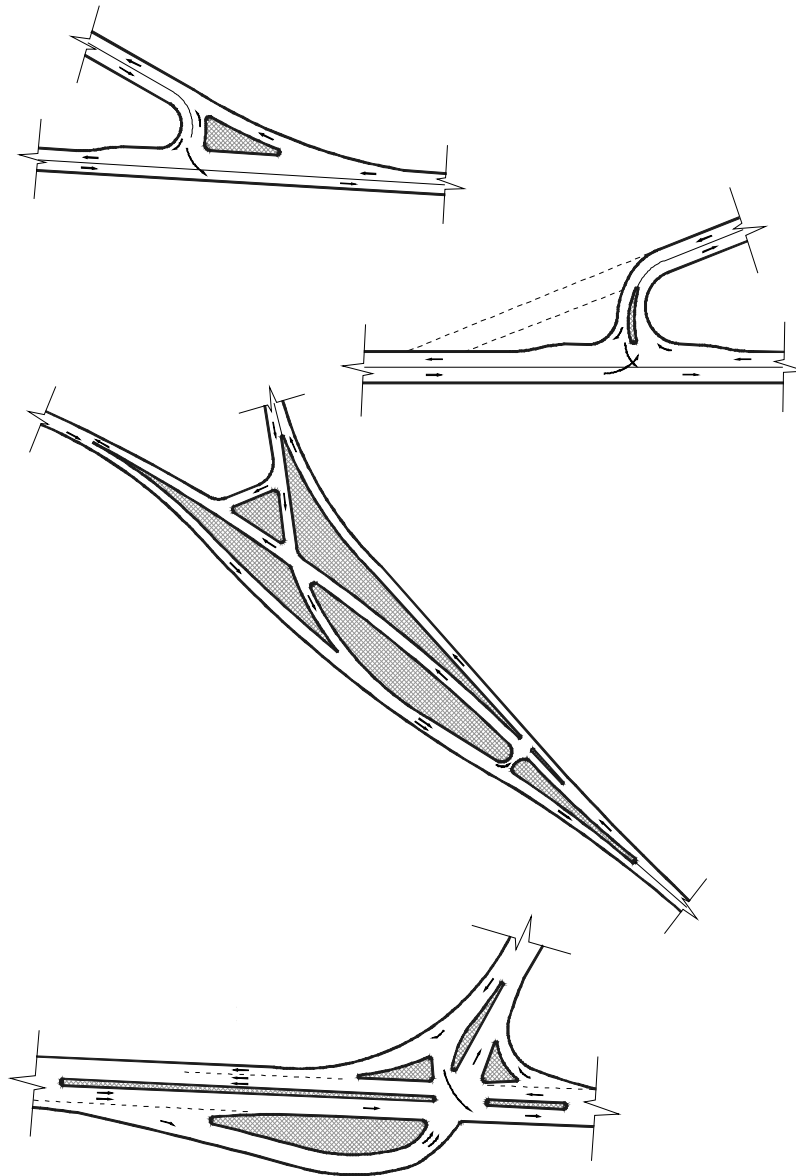
- Intersections with five or more branches and more or less equal traffic volume on all of them;
- Relatively large flows going around, exceeding the flow travelling straight;
- Extensive flat land available at a low price;
- Little pedestrian traffic; and
- Sufficient distance between each pair of consecutive branches to enable traffic to weave together. The capacity of the roundabout is determined by the most critical of its segments.

Figure III.1  
**“T” INTERSECTIONS**



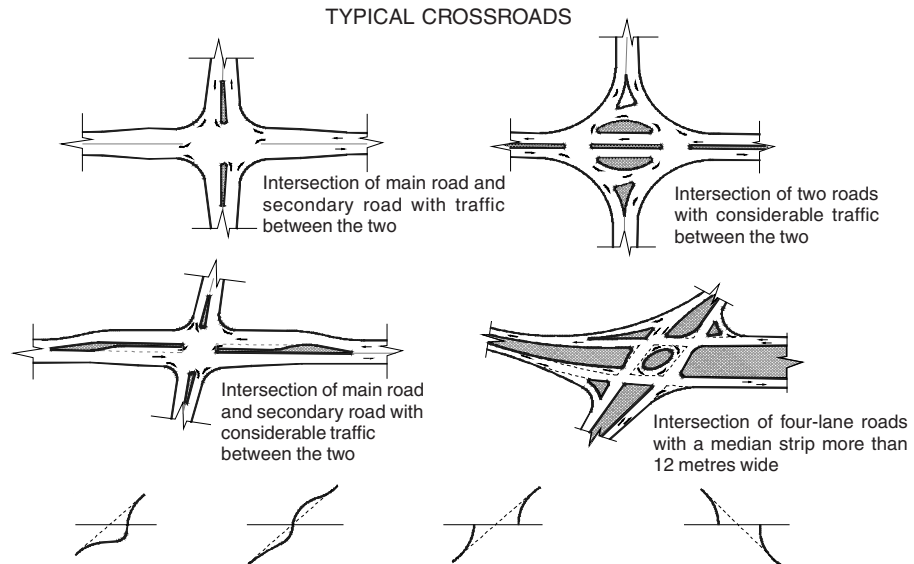
**Source:** Ministry of Planning and Cooperation (MIDEPLAN), *Recomendaciones para el diseño del espacio vial urbano*, Santiago, Chile, 1998.

Figure III.2  
“Y” INTERSECTIONS



**Source:** Ministry of Planning and Cooperation (MIDEPLAN), *Recomendaciones para el diseño del espacio vial urbano*, Santiago, Chile, 1998.

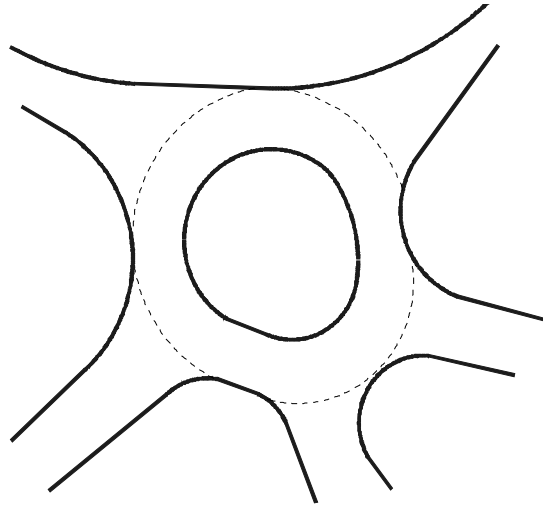
Figure III.3  
**CROSSROADS**



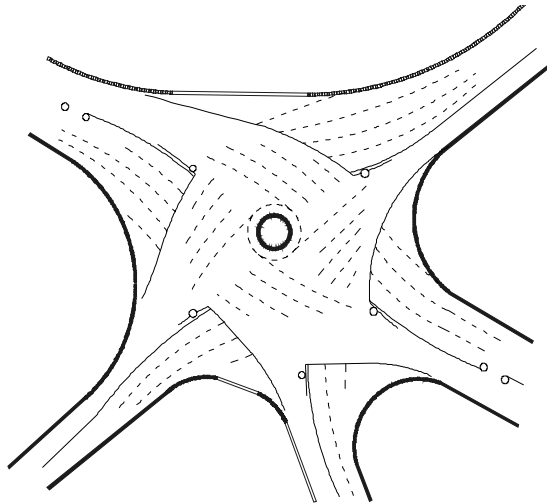
**Source:** Ministry of Planning and Cooperation (MIDEPLAN), *Recomendaciones para el diseño del espacio vial urbano*, Santiago, Chile, 1998.

Figure III.4  
**ROUNDBABOUTS AND MINI-ROUNDBABOUTS**

Before: capacity 4,300 vehicles



After: capacity 5,300 vehicles equivalent/hour



Saturation flow = total flow when there are queues at every branch  
("Cardiff Roundabout" experiment, May-June 1969, Road Research Laboratory)

**Source:** Ministry of Planning and Cooperation (MIDEPLAN), *Recomendaciones para el diseño del espacio vial urbano*, Santiago, Chile, 1998.

## 2. Intersection design

Because they have the potential to become congested, intersections should be carefully designed. In general, in urban areas the predominant criterion for intersections will be to increase their capacity, since it is normal for them to reach saturation during some periods of operation. This effort necessarily involves physical and operational aspects that must be addressed simultaneously.

### (a) Basic design principles

Any design must be carried out with the following fundamental criteria in mind (MIDEPLAN, 1998a):

- Preference for principal movements  
The most important movements should be given preference over secondary ones, allowing the road highest up in the hierarchy continual operation. This means that secondary traffic must be limited by means of adequate signposting, width restrictions, tight curves and even the total elimination of very minor flows.
- Reduction of conflict areas  
It is common for broad paved surfaces to operate like a “no man’s land” and thus for pedestrian and vehicle traffic to be disorderly. This creates confusion among drivers, which increases the number of accidents and reduces the intersection’s capacity. These broad areas are typical of oblique intersections and are one reason why they are not recommended.
- Perpendicularity of roads meeting at the intersection  
It is desirable for intersections to have right angles, which keeps areas of conflict to a minimum. Right angles also mitigate the seriousness of accidents that do occur and facilitate maneuvers, since they allow drivers a better view of their own position in relation to other vehicles. This principle is less important for intersections with traffic signals.
- Separation of conflict points  
By adequately channelling movements, points of conflict at an intersection can be separated, thereby obviating the need for drivers to pay attention to several different vehicles at once. In intersections regulated by traffic signals, it may be appropriate to concentrate some points of conflict, since separation in time can replace separation in space.
- Separation of movements  
When there is a significant volume of traffic on one road of an intersection, separate thoroughfares should be devoted to each direction of travel whenever possible, complemented by acceleration or deceleration lanes if necessary. The islands placed between the roadways for this purpose are also necessary for the placement of signals in many cases.

- **Speed control**  
Channelling can also control the speed of traffic entering an intersection by means of sufficiently sharp curves or narrowing of the roadway, which not only force drivers to reduce their speed but also prevent passing in areas of conflict.
- **Control of turn lanes**  
Channelling can prevent turning at inappropriate places, with islands that make turning physically impossible or very difficult. Islands are surfaces in the interior of an intersection where vehicles are prohibited from entering by lines or physical barriers. Safety is greater when islands are elevated than when channelling is effected by lines painted on the pavement, provided that the elevated surfaces do not reduce capacity or constitute hazardous obstacles.
- **Creation of protected areas**  
Islands give pedestrians and vehicles protected areas where they can wait to cross. In addition, if a pedestrian or vehicle needs to cross several lanes, this can be done one section at a time without having to wait for traffic to be stopped at all of them. A typical example is left-turn lanes in median strips.
- **Visibility**  
Visibility should determine whether vehicles entering an intersection are required to slow down or stop entirely. A vehicle on a secondary road should have sufficient time to slow down before reaching a conflict point if another vehicle appears on the primary road. Section 3 below provides more detail on this subject.
- **Simplicity and clarity**  
Complicated intersections that confuse drivers are not appropriate; channelling should not be too complicated or force vehicles into excessively inconvenient or roundabout maneuvers.

In the intersection treatments depicted in figures III.1 through III.4, the application of the principles outlined here can be seen.

Important design principles are channelling of movements, visibility, perpendicular placement of conflicting movements and creation of safety zones for pedestrians and vehicles.

#### **(b) Information required**

The information required to design an intersection is outlined in general in MIDEPLAN (1998a):

- Type of roads meeting in the intersection, as the treatment must be appropriate for their functional characteristics: classification, designed speed and right of way.

- Topography and structures: existing restrictions to surface expansion must be examined. Underground utilities (pipelines) must definitely be taken into consideration.
- Traffic: the volumes of each movement throughout the day must be ascertained in order to determine the capacity of the corresponding stretch of road. In addition, the movement of heavy vehicles must be determined and the vehicle type for which the intersection is to be designed must be established. An analysis of pedestrian usage of the intersection can contribute to decision making on any special facilities to be established for them.
- The number of accidents should be ascertained to reach decisions on what special measures, if any, need to be taken. For this purpose, it is important to determine how the accidents occur and what causes them.

### **(c) Design procedures**

In the last few decades, a number of computer models have been developed to assist in the design effort. These models, in turn, have specific data requirements that must be added to those mentioned above. Thus, intersection design can be viewed as an iterative process in which physical and operational changes can be modelled at low cost and their performance tested. A wide range of options can be explored and high-quality solutions achieved. The simulation of each option's operational results also facilitates the economic evaluation of the most appropriate alternatives, so that the solution with the best economic attributes can be chosen.

To enlarge capacity, it is recommended that islands be kept to the smallest size necessary to protect vehicles undertaking certain movements; in addition, the number of lanes should increase as each road approaches the intersection to achieve the maximum rate of vehicle clearance or discharge.

Another element to be taken into account in cities is the location of bus stops. They cannot be too far away from key intersections, as these are precisely where passengers will want to transfer, but neither can they be so close to intersections that their operations are hampered.

## **3. Intersection control systems**

As mentioned earlier, intersections tend to impose an operational restriction on a roadway. Therefore, the control systems put in place to regulate the right of way should respond to both the needs of the specific location and the general criteria of the axis or network in question.

Basically, intersections can operate with priority signposting (prioritized intersection) or traffic signals (signalized intersection). The former are governed by stop signs and the latter by signal lights.



### (a) Prioritized intersections

These intersections regulate the right of way with yield or stop signs.

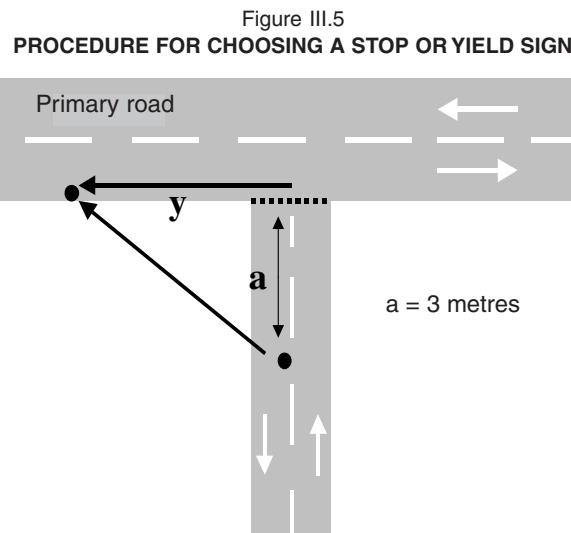
The yield sign tells drivers who encounter it that the vehicles on the other road have priority; they do not need to stop if the flow of traffic on the main road allows enough room for them to cross or turn onto that road safely. This sign should be installed in all cases in which visibility is not restricted, according to the criteria listed below.

The stop sign is intended to instruct drivers to bring their vehicles to a complete stop and to resume motion only when they can do so without causing an accident. It should be placed on the line where the vehicles must stop, in such a way that the driver can see the main road well enough to pull out safely.

The criteria for determining which sign to use are as follows:

- A priority sign should be used when the volume of traffic reaching an intersection from all branches exceeds 100 vehicles per hour at any point in the day.
- The type of priority sign depends on visibility conditions. A yield sign is called for if a driver on the secondary road can see any vehicle approaching on the other road with enough time and space for him to enter the intersection before it arrives. If not, a stop sign should be used.
- In general, stop signs should be used sparingly, since indiscriminate usage detracts from their credibility and when they are really needed, they may actually reduce the safety of an intersection rather than enhancing it.

The following procedure should be used (see figure III.5):



**Source:** Ministry of Transport and Telecommunications, *Manual de Ingeniería de Tránsito*, Santiago, Chile, 1985.

- At the level of the pavement edge of the primary road, an imaginary line “a” is drawn three metres along the centre line of the secondary road.
- Another imaginary line “y” is drawn from the central axis of the secondary road, in the opposite direction to the flow of traffic, for a length determined by the maximum speed limit on the primary road, as indicated in table III.1.
- The yield sign is used if, from any point along line “a”, visibility is uninterrupted for more than one metre along line “y”. If it is not, a stop sign should be used.

If the primary road has two-way traffic, this procedure must be carried out separately for each direction and a stop sign should be installed if it is warranted in at least one direction.

The installation of a stop or yield sign should always be accompanied by the corresponding marking of the pavement.

Whether to install a stop sign or a yield sign depends on visibility, not on the relative importance of the roads.

Table III.1  
CRITERIA FOR INSTALLING A STOP SIGN

Maximum speed limit on the primary road (in km/h)	Visibility of the primary road from the secondary road (in metres)
More than 90	Use stop sign
90	< 180
80	< 140
70	< 120
60	< 90
50	< 70

**Source:** Ministry of Transport and Telecommunications, *Manual de Ingeniería de Tránsito*, Santiago, Chile, 1985.

## (b) Signalized intersections

Traffic signals are a more sophisticated means of controlling an intersection. They make it possible to separate the periods of time when the traffic flowing on each road can cross the intersection. The allocation of times is called “distribution”, and the cycle is the time elapsed from the beginning of a phase until that phase is reactivated.

In general, traffic signals are considered a positive development that yields benefits and enhances safety in any situation. This belief is not always corroborated, however. To provide real benefits to the population, a number of conditions must be present so that the benefits of a traffic signal are actually greater than the costs. For example, given the variability of demand, it is possible that a traffic signal may be fully justified during certain periods of the day or certain seasons of the year, but represent a cost to the community at other times.

A cost-benefit analysis is a complex technical task that can be made easier with the support of computer models. To simplify the analysis, however, various countries have adopted minimum requirements or standards to justify the installation of traffic lights. If these requirements are met, the right decision is usually made. They include, among other factors, vehicle volume, pedestrian volume and accidents (MINTRATEL, 1985).

- Justification by vehicle volume

Table III.2 shows the minimum vehicle volumes that must be met for the installation of traffic signals:

Table III.2  
**JUSTIFICATION OF A SIGNAL BY VEHICLE VOLUME**

Number of lanes in each incoming branch		Minimum volumen (vehicles/hour)	
Main artery	Secondary artery	Main artery both roads	Secondary artery road with most incoming traffic
1	1	500	150
2 or more	1	600	150
2 or more	2 or more	600	200
1	2 or more	600	200

**Source:** Ministry of Transport and Telecommunications, *Manual de Ingeniería de Tránsito*, Santiago, Chile, 1985.

The values in table III.2 should be true for the eight-hour period with the highest demand on an average day.

- Justification by delays in access from the secondary road

This requirement applies when the vehicles coming in from the secondary road experience excessive delays. It is illustrated in table III.3.

Table III.3  
**JUSTIFICATION OF A SIGNAL BY DELAYS IN SECONDARY ACCESS**

Number of lanes in each incoming branch		Minimum volumen (vehicles/hour)	
Main artery	Secondary artery	Main artery both roads	Secondary artery road with most incoming traffic
1	1	750	75
2 or more	1	900	75
2 or more	2 or more	900	100
1	2 or more	750	100

**Source:** Ministry of Transport and Telecommunications, *Manual de Ingeniería de Tránsito*, Santiago, Chile, 1985.

The values in table III.3 should be true for the eight-hour period with the highest demand on an average day.

It is clear that this condition is not intended to minimize total delays, just to reduce unusually long delays for vehicles on the secondary road.

- Justification by progressive movement

Occasionally it is appropriate to install a traffic signal to ensure progressive movement of vehicles along a thoroughfare. In practice, incorporating a traffic light makes it possible to keep vehicle formation compact, thus guaranteeing that most of the flow benefits from the measure. This criterion, which is valid for all vehicles in general, should be revised if there is a significant presence of mass transit vehicles. In that case it is very difficult for buses to join and remain in the formation of motor vehicles, because they must make stops to drop off and pick up passengers.

- Justification by accidents

This criterion enters into play when there is a clear risk of accidents at an intersection, for example, if five or more major accidents have occurred in each of the last three years.

The installation of a traffic signal does not guarantee a reduction in accidents. It may even increase them if the light greatly inconveniences drivers at an intersection. If that is the case, they may ignore the light, considerably escalating the risk of accidents.

Beginning in the 1980s, a variety of computerized tools have been developed to assist in the design of traffic signal cycles and distribution. Among the most noteworthy are SIGCAP, which uses linear programming to maximize the signal's practical capacity; SIGSET, which uses non-linear programming to minimize delays; SQGN, which analyses different phase sequences; and SIGGAT, which makes it possible to calculate phases and cycles at saturated intersections.

At present, SIDRA is one of the most widely used tools for analysing isolated intersections, whether they are controlled by signal lights or priority signs. SIDRA employs detailed transit analysis models and an iterative approximation method for estimating transit capacities and statistical indicators: delays, length of queues, stoppage rate and others. Although SIDRA is a package for analysing isolated intersections, it can be applied to situations in which traffic lights are synchronized, provided the statistical distribution of vehicle flows in the intersections are specified.

## **C. ACTIONS ON ROADWAYS**

### **1. Expansion of physical capacity**

Arcs are stretches of roadway between intersections. Normally they do not give rise to major conflicts.

There may, however, be situations in which an arc becomes a bottleneck within a succession of arcs and intersections. The most appropriate solution is to expand their physical capacity. Increasing the capacity of the entire roadway axis may also be considered, if a significant expansion of the roadway supply is contemplated. In this case, there is competition from alternative uses of public space and even private space if expropriations are necessary.

From the standpoint of controlling congestion, it is worth noting that increases in physical capacity such as the latter option above tend to provide only short-term solutions to imbalances between supply and demand, since pent-up demand resulting from the congestion itself tends to become fully expressed in a relatively short time, as a more fluid and expeditious operation attracts more traffic.

Thus, congestion has a tendency to regenerate itself with higher flow levels. If this trend takes hold, it can end up committing public space to motorized transport, to the exclusion of pedestrian traffic and other activities in that space. This phenomenon is especially acute in cities that have consciously or unconsciously chosen to provide greater capacity in response to increased flows. Other cities, in contrast, perhaps because of the special significance of their architectural or historical heritage, have explored alternatives to generating more capacity without allocating significant amounts of new land for vehicular use.

The traditional expansion of physical capacity is thus being replaced by more efficient ways of using that capacity. Naturally, synchronizing traffic lights appears to be the best option for improving speed on thoroughfares, thus reducing travel times and congestion (see section D below). But another

Expanding transport supply involves more than just physically enlarging motorways, but encompasses a broad range of efficient and sustainable solutions to the problem of congestion.

possibility is to change the direction of traffic on arcs or roadways during certain hours of the day as a function of the principal movements of commuters. And still another is to assign lanes by type of vehicle, facilitating the travel of those that make the most efficient use of space, namely, mass transit vehicles.

This method of increasing capacity can also attract new vehicles to the flow and soon the new facilities are pushed to the limit again. Therefore, explicit consideration of the modes of transportation favored by the improvement should also be part of the analysis and medium- and long-term projections.

## 2. Reversible-flow roads

Reversible-flow roads are those that change the direction of traffic throughout the day depending on the volume in each direction, with a view to enhancing flow in the direction with the higher volume. The direction of traffic can thus be reversed on a one-way street, or a two-way street can be turned into a one-way street, temporarily providing greater capacity for accommodating the massive flows that characterize the travel patterns and general operating rhythm of cities. These movements tend to occur, for example, from residential areas to places of work or study during peak hours in the morning and vice-versa during peak hours in the afternoon.

This finely tuned management of existing capacity makes more intensive use of the principal roadways by accommodating the greatest flow of traffic. In many cases, this measure significantly enlarges the transport supply in order to meet rush-hour needs.

In 2001, Chilean transportation authorities implemented a number of transit management measures, among the most noteworthy being the variation of traffic direction on six major axes in the city. Substantial results were obtained (see table III.4).

Table III.4  
**SANTIAGO: TIME SAVED ON REVERSIBLE-FLOW ROADS**

Road	Length (km)	Travel times before implementation (minutes)	Travel times after implementation (minutes)	Savings (%)
Portugal	1.4	10.2	3.0	70.6
Salvador	3.1	12.2	7.3	40.2
Diagonal Oriente	5.5	17.5	11.2	36.0
Bascuñán	0.2	5.9	2.5	57.6
Mapocho	3.7	3.2	2.8	12.5
Av. El Cerro	1.8	6.2	3.9	37.0

**Source:** Office of the Under-Secretary for Transport of Chile.

The figures show an average savings of 43% on travel times on reversible-flow roads during the morning rush hour. Diagonal Oriente and Salvador are the most notable cases, as significant savings in travel time were reported even though vehicular traffic grew by up to 40%.

The directly-measurable benefits on the roads in question are clearly immense. The following considerations should be noted, however:

- These changes on the city's main arteries caused drivers wishing to go in the opposite direction to divert to other routes, thus having to travel longer distances and ultimately experiencing additional delays in reaching their destinations. All of this should be taken into account in the design and evaluation of the measure; and
- The scheduling of directional changes requires extremely reliable data and adequate signalization to avoid confusion and accidents, especially during the switch.

#### **D. SYNCHRONIZATION OF TRAFFIC LIGHTS**

Synchronizing traffic lights is one of the most efficient ways to cut delays, fuel consumption, pollution and accidents. Synchronization consists of setting up cycles, distribution and phasing of lights along a road or within a network so that vehicles can move at a certain speed, with minimal delays caused by red lights.

Synchronizing traffic lights can yield major savings in time, fuel and pollution.

The most important parameters to be taken into consideration for synchronizing a system are the cycle, which will normally be common to all the synchronized lights, the distribution of green light times and the time lag, that is, the period between the beginning of a specific phase of one signal and the beginning of that same phase at the next intersection.

In addition to these basic parameters, there are a number of conditions that must be determined as the complexity of the axis or network increases. This whole task can be facilitated with modelling tools designed to represent and optimize each case.

The basic unit of synchronization is an axis, corridor or roadway. Simple one-way axes can be synchronized using graphic techniques or "green banding", usually by developing fixed programming calculated on the basis of historical data on flows and velocities. But in the case of two-way thoroughfares with irregularly spaced intersections, it may be difficult if not impossible to set up an uninterrupted "green band" that meets demand. Of course, the synchronization of networks is outright impossible to carry out using this method.

In the last 30 years an extraordinary development of technology has resulted in the incorporation of computers and electronics into the management of complex traffic situations. It is now possible to control vast networks with centralized, flexible, demand-oriented systems. Programs such as SIGOP, COMBINATION METHOD and TRANSYT have completely changed the approach to the problem, providing previously unsuspected capacities to achieve the maximum potential of transit systems. In particular, TRANSYT has been widely tested in many countries and has become a veritable international standard for network synchronization.

Current technology makes it possible to synchronize traffic signals precisely and economically.

### **1. Synchronization with fixed plans**

This method requires traffic light controllers with sufficient capacity to receive and run instructions from pre-established plans. The plans are generated externally by measuring flows. Ideally, the number of plans should equal the number of significant operational periods that can be detected. In this case, it is essential that each controller have clocks that function with the frequency of the network or high-precision quartz clocks, so that the lag time can be programmed adequately and maintained over time. Alternatively, a cable connection between controllers may be considered, in which case the system would function with a common clock.

Synchronization with fixed plans arose at a time when computing, communications and detection technology were not sufficient to provide solutions more suitable for complex situations of variable demand and interaction among networks. This does not mean that this method is necessarily obsolete. A case-by-case analysis will reveal whether a given control need can be addressed with fixed plans, meeting both demand and cost needs.

### **2. Flexible or dynamic synchronization**

Flexible, demand-driven synchronization solutions are useful in areas of intensive use, which are usually subject to unpredictable interferences. This method is based on real-time detection of significant flows reaching each intersection. The data are processed online by a central computer that generates updated signal cycle plans, which are then transmitted to the controller at each intersection.

The system is quite sophisticated, so in addition to a central computer programmed with appropriate software and traffic signals with controllers capable of following instructions, there must be direct communication between the central computer and the controller at each intersection.

Some of the best known options of this sort are the United Kingdom's SCOOT and the Australian SCAT systems.



### 3. Centralized control systems

A more technologically complex option is a centralized traffic-light control system that opens up the possibility of using different modes of control to meet given areas' differing requirements. This means that, for example, a dynamic control system could be used in a city's downtown area but need not be applied to the entire traffic light system or to intersections that should not be coordinated with others because they do not form part of any functional network.

Having centralized control allows for the entire system to be administered in accordance with the needs of each part. In addition, the following features are possible:

- Direct communication with each signal controller for the purpose of regulating traffic;
- Direct communication with each controller for monitoring errors;
- Implementation of emergency plans for the circulation of special vehicles;
- Administration of signs displaying variable information to advise drivers on the condition of the route and, in special cases, to generate detour routes; and
- Administration of television cameras for the direct observation of conditions in intersections or key axes.

In other words, when there is communication between the central computer and each controller, the possibilities for managing traffic are extended to aspects not necessarily linked to the traffic signal programs. This paves the way for a more integrated management of the intersections and networks in question. A centralized traffic control system allows for not only the synchronization of axes or networks of traffic lights, but also a comprehensive management of circulation problems using television cameras, variable driver advisory signs, remote detection of errors and management of emergencies.

A centralized traffic control system allows for the comprehensive management of circulation.

In general, centralized traffic control systems are projects that yield tremendous social benefits when correctly designed and applied in cities with road congestion. The system in Santiago has been particularly successful; its development followed a rigorous process of analysis and evaluation of alternatives, after which implementation took place in stages. It is currently functioning and enabling drivers to achieve significant savings in travel time. The best evidence of the effective service rendered was seen in the chaos and tremendous congestion that ensued when the computers controlling the system went down.

## **E. EXCLUSIVE LANES AND STREETS FOR MASS TRANSIT**

An important measure for giving priority to public transportation is to reserve road space for its exclusive use. Traffic signals must be programmed in conjunction with this measure so that buses are given priority. Clearly there is no need to modify the size and characteristics of mass transit vehicles, but improving the circulation of these vehicles does in fact expand their capacity. This increase could attract commuters from other modes of transportation and lead to a balanced use of motorways that is more in keeping with the general interest.

Reserving space for buses is a regulatory move that is designed to correct, through the administration of the motorways, the distortion caused by an erroneous perception of congestion by individual drivers. If motorists knew the total cost of operating their vehicles in congested conditions and if bus passengers knew as well, changes in the allocation of the transport supply would make the kind of intervention proposed here practically unnecessary, since a new balance with smaller flows would be created. Absent this development, the authorities intervene by distributing lanes on a given thoroughfare with a view to ensuring adequate service for mass transit and incidentally eliminating friction between buses and other vehicles.

Documented international experience generally reveals significant benefits from this type of initiative, although how much of an advantage is yielded depends on the quality of the design. In Europe the experience has been positive. In Latin America, when signs of congestion first appeared, some major cities implemented these measures as well, with the added bonus that the majority of travel still takes place on public transit.

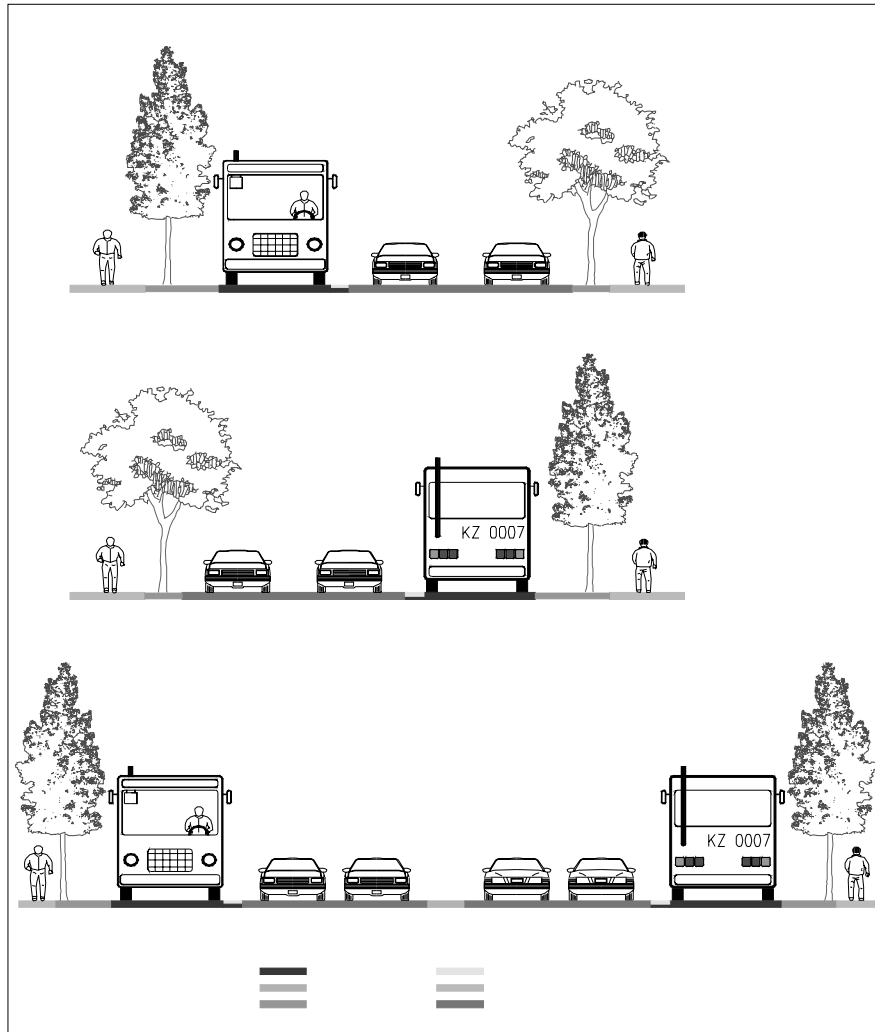
Some of the methods of reserving space for public transport are discussed below.

### **1. Bus-only lanes**

These are lanes that allow only buses to circulate, normally indicated with pavement markings. They are characterized by the low cost of implementation, but their actual results—except in the case of lanes in which buses go against traffic—depend on the willingness of drivers to comply, and investment in prolonged law enforcement efforts is required. It is not always possible to impose discipline in the use of these lanes; sometimes the measure is invalidated by the systematic violation of the restrictions.

Figure III.6 shows three examples of bus-only lanes. In the first case, a one-way street has a bus-only lane on the right. This is the most widely used variant. The second example is the same except that the bus travels against the traffic, which prevents other vehicles from using the lane. The third case shows a two-way street with bus-only lanes on the outside.

Figure III.6  
**THREE EXAMPLES OF BUS-ONLY LANES**



**Source:** Ministry of Planning and Cooperation, *Recomendaciones para el diseño del espacio vial urbano*, Santiago, Chile, 1998.

In general, right-hand bus-only lanes have the advantage of providing access to the sidewalk and are recommended when the surrounding area is characterized by retail or service businesses that generate considerable incoming and outgoing traffic. This lane configuration tends to be violated by private vehicles that are just as attracted by the proximity to adjacent businesses (which are separated from their designated travel lanes by the bus-only prohibition) or that must enter these lanes to make right turns. Therefore, this type of lane requires abundant and constant enforcement patrols.

## **2. Segregated bus lanes**

Segregated bus lanes are similar to bus-only lanes in that they are exclusively for the circulation of mass transit vehicles, but the difference lies in the fact that there is a physical barrier between them and the space allocated to other vehicles. The barrier prevents other vehicles from entering, thereby allowing buses to travel more freely.

Segregated bus lanes are a much more elaborate and costly solution than bus-only lanes. In some cases private transport must be restricted significantly and in other cases major expropriations are required, but the net benefits that have been documented support their implementation and incorporation as a standard criterion of transport system design.

It is common for segregated lanes to be placed in the centre of the roadway in order to ensure that private vehicles have access to both sides and to facilitate right-hand turns. This is not necessary if there is a park, railroad or other property along the side of the thoroughfare that does not require vehicle access from the street, or if there is a local road precisely for the purpose of providing such access.

Segregated lanes can be one-way or two-way, with one or more in each direction and with or without an extra passing lane where bus stops are located. Those placed in the centre of the roadway often have bus stops placed on alternating sides to make better use of the width of the pavement. When there are long stretches without stops, the excess room can be used for a median strip, for a narrower paved section or for special left-turn lanes.

Although these measures do yield considerable benefits for mass transit, it is important for the design to take into account the hindrances caused by the separation in the form of problems making turns, restricted access to adjacent properties and an eventual reduction in capacity for private vehicles.

The segregated bus lanes set up on the Alameda Bernardo O'Higgins in Santiago are an interesting case (see table III.5). The avenue has two five-lane thoroughfares, and since the late 1970s more and more of them have been designated exclusively for buses. Originally there were two bus-only lanes in each direction, labeled with markings on the pavement. At present, buses have three lanes in each direction, separated from other traffic by physical barriers that make encroachment extremely difficult.

Table III.5  
**TIME SAVINGS ON A SEGREGATED LANE IN SANTIAGO  
(MORNING RUSH HOUR)**

Avenida B.O'Higgins (7.0km) direction	Bus travel time				Auto travel time			
	Before imple- ment- ation (minutes)	After imple- ment- ation (minutes)	Saving (minutes)	Savings (percent- ages)	Before imple- ment- ation (minutes)	After imple- ment- ation (minutes)	Saving (minutes)	Savings (percent- ages)
Westbound	28.0	17.4	10.6	37.9	17.5	12.1	5.4	30.9
Eastbound	33.0	21.6	11.4	34.5	21.0	23.5	(2.5)	(11.9)

**Source:** Office of the Under-Secretariat for Transport of Chile.

It can be seen that travel times diminished by approximately 36% for buses, while cars experienced savings or delays, depending on the direction of travel. Westbound cars saw travel time reduced by 5.5 minutes, while eastbound cars increased their travel time by an average of 2.5 minutes.

### 3. Bus-only streets

Bus-only streets are entire motorways devoted exclusively to mass transit.

Cars may also benefit from segregation.

Although from the standpoint of physical design this method seems simple in principle, requiring only adequate signposting to function, in operational terms it tends to have a major impact because of the redirection of private vehicle traffic and the limited access to adjacent properties.

Bus-only streets have been a permanent fixture in different countries for many years. The method of establishing that exclusivity for only certain periods of time seems to be a recent innovation, however. It has been tried in Santiago as part of the whole set of projects implemented in 2001 to reduce congestion. This method involves granting buses an entire street for their exclusive use, but only during peak hours, after which the street returns to mixed traffic. The streets in this programme are part of the main network in the city of Santiago. Travel times before and after implementation are shown in table III.6.

Table III.6  
**TIME SAVINGS WITH BUS-ONLY STREETS IN SANTIAGO  
(MORNING RUSH HOUR)**

Bus-only street	Length (km)	Direction	Travel time before imple- ment- ation	Travel time after imple- ment- ation	Savings	
			(minutes)	(minutes)	(minutes)	(percent- age)
Gran Avenida	9.4	Northbound	38.4	29.3	8.1	23.7
Gral. Carrera		Southbound	26.8	28.4	(1.6)	(6.0)
Recoleta	4.3	Northbound	14.1	12.8	1.3	9.2
		Southbound	17.1	14.4	2.7	15.8
Santa Rosa	10.5	Northbound	40.4	33.6	6.8	16.8
		Southbound	24.6	26.2	(1.6)	(6.5)
Pajaritos	7.8	Westbound	17.7	17.4	0.3	1.7
		Eastbound	22.7	19.6	3.1	13.7
San Pablo	9.6	Eastbound	33.9	25.4	8.4	25.0
Independencia	5.9	Southbound	17.3	17.2	0.1	0.5
Vicuña Mackenna	9.3	Northbound	26.2	23.4	2.8	10.7
		Southbound	22.6	23.3	(0.7)	(3.1)

**Source:** Office of the Under-Secretary for Transport of Chile.

The data show that the average savings in travel time is approximately 10%; subsequent measurements brought this figure up to as much as 13%. Moreover, it is interesting to note that in cases such as southbound Gran Avenida, westbound Pajaritos and southbound Vicuña Mackenna, which have light traffic during morning rush hour since they lead away from downtown, the benefits of the measure are marginal and even negative, which suggests that the bus capacity could be excessive, or that in fact there was no problem before.

Initial measurements on the alternate routes used by cars, such as Vivaceta (the alternate for Independencia) and Avenida Las Industrias (the alternate for Vicuña Mackenna), revealed an increase in travel times. Consequently, complementary measures such as reversible-flow lanes were adopted to accommodate private vehicles more effectively.

It can thus be concluded that preparations for implementing these measures should include mass information campaigns warning drivers and the population in general of the changes and suggesting alternate routes and detours to mitigate any negative impact that might occur.

#### **4. Public transit reorganized with the equivalent of a surface subway**

Segregating lanes for buses can achieve an even greater dimension if public transit on these lanes is reorganized in a system equivalent to a surface subway. Various experiments were tried in Brazil involving not only separating bus traffic but also building stations, developing an integrated fare system and setting up transfer terminals. These systems have given rise to a truly new mode of transportation that is very similar to a subway system, with the added bonus that the costs of putting it into service are several times lower.

A paradigmatic case that has inspired subsequent experiments elsewhere in the region is that of Curitiba, Brazil. Begun in the 1970s, this programme established a concept of mass transit that includes bus-only lanes

The best known recent trials with bus priority lanes have used an integral transport approach and have been modelled on the system used in Curitiba.

and special stops, “tube stops”, with raised platforms level with the bus’s floor. This makes it easier for passengers to board and also prevents anyone from getting on or off the vehicle at an inappropriate place. There is also a pre-payment system, with tickets being sold before getting on the bus and integrated fares between trunk and feeder services.

The project in Curitiba was followed by others in Brazil and other countries. A noteworthy example is that of the trolleybus system in Quito, Ecuador, which went on line in 1995 and was subsequently expanded (Arias, 2001). It is characterized by a bus-only street with a lane 3.5 metres wide in each direction, pre-pay stations and bus-level platforms designed to minimize time spent getting on and off. Travel time studies conducted before and after implementation of the project revealed an average of up to 50% savings.

Box III.1

**BOGOTÁ'S TRANSMILENIO SYSTEM**

A particularly important instance of the reorganization of transport using exclusive motorways is the so-called "Transmilenio" in Bogotá, Colombia. The first phase of this project (Calle 80, Avenida Caracas and Autopista Norte) was opened in December 2000. Service is structured as follows:

- High-speed trunk services (average speed is 25 kilometres per hour) fed by buses connecting the various neighbourhoods near the terminal stations, providing service at predetermined frequencies.
- The trunk services operate on segregated lanes. The first phase, already in operation, consists of 38 kilometres, with 53 regular stations, 4 intermediary stations and 4 terminals. The latter two types of station are designed as connectors to other public transit lines.
- Articulated 160-passenger buses that have local routes (stopping at all stations) or express routes (stopping only at some stations).
- Prepayment system with smart cards, run by a company that specializes in this service. Bus drivers are paid approximately US \$1.40 per kilometre.
- Central management control and Global Positioning System (GPS) for tracking buses.
- The infrastructure cost US \$6.8 million to build and the total investment, including rolling stock, amounted to US \$9.4 million per kilometre. These figures are much lower than what a subway system would cost.
- "Scrapping" of an average of 2.7 old buses for each articulated bus. This rate is expected to rise to four when new lines come into operation.

The Transmilenio system has operational characteristics similar to those of a subway system. A year and a half after opening, it carries some 700,000 passengers each workday, exceeding previous estimates.

Transmilenio is being viewed in the community increasingly not only as a transportation initiative, but also as a city development initiative. Thus, after the successful inauguration of the system, the investment plan will continue as projected, involving a total of 387 kilometres and total infrastructure investment of US \$1.97 billion.

**Source:** E. Sandoval, "Concepto integral del espacio público y la movilidad urbana. Enfoque de la ciudad de Bogotá. Caso específico: sistema Transmilenio", document presented at the Caracas International Seminar, 2001; and electronic edition of the newspaper *El Tiempo*, "15 buses más para TM"; (<http://eltiempo.terra.com.co/bogo/2002-07-25/index.html>), 25 July 2002.



## **F. HIGH QUALITY PUBLIC TRANSIT SYSTEMS**

### **1. Executive buses**

One possibility for encouraging drivers to abandon their cars for routine trips such as commuting to work is to institute high quality multi-passenger vehicles on regular routes. In some cities these have been called “executive buses” or “differential buses”. Available on the market is a broad and diverse range of buses and minibuses that offer a high degree of comfort and are designed for use in tourism or business travel. The vehicles most suitable for urban mass transit can be selected from among them.

Their potential contribution to decongestion lies in their attraction of motorists rather than conventional bus riders. There is solid evidence that differential services offered in various Latin American cities, such as Buenos Aires and Rio de Janeiro, transport large numbers of passengers who used to drive in cars (ECLAC, 1995b), reducing congestion by improving the coefficient of space occupied per passenger.

### **2. Attracting drivers**

Obviously an executive bus service, no matter how high the quality, is not equivalent to the service provided by a car; but under certain conditions it could be preferred on the grounds of comfort, safety, reliability and travel time to destination, considering that travel time can be used to good advantage, for reading, for example (CIS, 1995). Although that is not the purpose, riders of conventional public transportation who are dissatisfied with it and willing to pay more for better service may also be attracted.

The conditions necessary for this service to be attractive are (ECLAC, 1995b):

- Relatively frequent and regular service (at least four times an hour)
- Routes corresponding to existing patterns of origins and destinations.
- Relatively high operating speeds, not very different from those possible in a car, but in any case higher than those of regular buses. This means more widely spaced stops. It would be even better if these vehicles travelled on segregated lanes or those giving priority to both conventional and executive buses, with preferences in traffic light cycles.
- Comfortable vehicles with pneumatic suspension, reclining seats, no standing passengers and trained, uniformed personnel.
- Other characteristics may include ambient music and air conditioning or heating, as required by the weather.

Another important consideration for attractiveness is for business organizations to be modern and efficient, with a positive image reflected in enthusiastic customer service, expeditious ticket sales, including the possibility of subscriptions, new well-maintained buses, appropriately designed bus stops

and, most significantly, following different criteria than traditional approaches (CIS, 1995).

Fares should be considerably higher than regular public transit fares, since higher quality vehicles are undoubtedly more costly. There are many examples in Latin America of slightly more expensive services that are unable, because of the cost restriction, to offer much different service, although with perhaps slightly faster travel times, in smaller vehicles. The result is that the public they attract comes from traditional buses rather than cars. This means more vehicles in circulation and hence more congestion and greater risk of accidents.

### **3. Are executive buses viable?**

In cities with a regulated transport system, it would be interesting to design these superior services and to grant concessions to operate them.

In cities with unregulated transport, executive buses may not emerge spontaneously, so some sort of impetus or facilitation may be necessary. It is unknown, however, whether the service would be profitable and sustainable, especially since it is not known what motorists' preferences would be or what advantages they would perceive. In addition, routes would have to be assigned appropriately, giving preference to high-income neighbourhoods.

One way of proving their viability would be to leave it up to the market; they would simply be allowed to emerge, with a high minimum fare being established as an essential condition for truly differentiating them from regular services. In this regard, it is helpful not to impose too many regulations with respect to bus size or specifications, frequencies, routes or other aspects. On the contrary, entrepreneurial initiative should be given the freedom to adapt to users' requirements. It would also be helpful to allow differential buses to operate only Monday through Friday, with other services being offered to tourists on the weekends.

### **4. Collective taxis**

Another high-quality mass transit option is represented by collective taxis, which are widely used in many cities. They offer fixed routes and charge a higher fare than buses. Their advantage lies in the fact that, being cars and carrying a small number of passengers, they can travel at a higher speed. Because they are a tight fit, however, they do not easily attract motorists and are more likely to attract people who would otherwise ride the bus.

## **H. RAILROAD OR SUBWAY SYSTEMS**

Among the grounds frequently cited to justify building an urban railway system is that it will reduce traffic congestion. The truth of that assertion is examined in this section. The term “subway” includes actual subterranean systems, known in some cities as the “underground”, as well as light rail trains (LRT) and urban and suburban trains.

### **1. A historical introduction**

In the middle of the nineteenth century, London barrister Charles Pearson asserted that an underground railway would alleviate traffic congestion in the British capital, where the number of travellers was already 750,000 persons per day (Howson, 1981). The private company that put the first London underground in service in 1863 certainly did not have the goal of alleviating congestion; however, it must have viewed that congestion and the high costs of street-level travel as economic justification for its project. Similar justification could be found for the private Anglo Argentina tramway company's investment in the first Latin American subway, which opened in Buenos Aires in 1913.

Later on, as public-sector participation in urban transport increased, congestion was also a consideration in the construction of subways, which were seen as a means of reducing it. A study in Latin America in 1927 concluded that building a subway could solve São Paulo's traffic problems (Hochtief, Monteral and Deconsult, 1968). It should be noted that at that time, every passenger-kilometre produced by mass transit generated much more congestion than today, since trams represented a tremendous obstacle to non-rail traffic on shared-use streets. Moreover, the first buses (or collective vehicles) had a low capacity per square metre of street space occupied, as well as limited acceleration and braking power.

By 1932, European urban architect Karl Brunner, referring to the situation in Santiago, stated that “traffic congestion and parking problems will remain in the city centre and within a few years building a subway, at least through the city centre, will be an urgent necessity that cannot be postponed” (Brunner, 1932). Judging by the words of that architect, it is clear that there were already signs that the car was contributing to congestion in Santiago.

Once the car emerged as the principal cause of congestion, given its heavy presence among transportation options, it became much less likely that building a subway could solve the problem (Thomson, 1997), as will be argued in the sections below. For example, it is estimated that by the middle of the 1920s in London, buses and trams accounted for at least 25% of the flow of traffic other than delivery or freight vehicles. Today, in contrast, using the city of Santiago as an example, the comparable proportion would be approximately 7% during rush hour.

## 2. Where do subway passengers come from?

In Latin America, according to surveys of declared preferences conducted in many cities beginning in about 1975, for trips on a single mode of transportation many commuters prefer the subway to regular surface mass transit, if the travel time is similar or even if there is a slight disadvantage in terms of fare. Before that time, although passenger preferences are not known due to the lack of data, very few would not have preferred travelling on a new subway to riding on the rudimentary, noisy buses, trams or multi-passenger vehicles of the time. Therefore, in the past, even more than now, a new subway would have attracted large numbers of former mass transit riders.

On the other hand, the car is preferred to the subway if travel time is the same, both because of its subjective attributes and due to its flexibility, privacy, ability to carry cargo, protection from the weather and other considerations. Consequently, a recently opened subway is much more attractive for people who used to ride the bus than for motorists. One of the most comprehensive studies on mass transit in cities in developing countries concluded that, typically, immediately after a subway begins operating, 81% of its passengers are former bus riders, 16% are people who simply did not travel on the axis and only 3% have switched from cars or motorbikes on the axis (Allport and Thomson, 1990). As a result, it is clear that there is a direct correlation between the significance of mass transit vehicles in the flow of traffic and the direct impact of the subway on congestion.

Empirical evidence suggests that Latin American subways that came on line in recent decades have had a minimal impact on traffic congestion. For example, in São Paulo it was found that “bus traffic fell by 500 per hour in each direction in the corridors in question, and although congestion was reduced at first, it later returned to serious levels”. In Santiago, “congestion remained serious on the principal east-west axis and bus traffic stayed near the maximum level possible”. In Porto Alegre, “there was no serious congestion before or after the opening of the suburban train system”; and in Mexico, “congestion caused by motor vehicles remained heavy, and although bus speeds were adequate, that was more attributable to the implementation of segregated lanes than to the subway” (Allport and J. Thomson, 1990). Evidence from cities in other regions is generally similar (I. Thomson, 1997). There have been cases in which modernized trolley or LRT systems have attracted significant numbers of motorists; this was true in Sheffield, where an exceptional 22% of passengers on the new trolley system had been commuting by car before (Hass-Klau and others, 2000). There is no guarantee, however, that the road space they free up will not be taken over by other drivers. Stories in the technical-popular press indicate that the new tram system in Croydon, a suburb south of London, has cut parking in the downtown area by 6%, while at the same time sales in businesses located there have climbed 11%.<sup>1</sup>

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<sup>1</sup> Published in the August 2002 edition of *Tramways and Urban Transit* of the Light Rail Transit Association in the United Kingdom.

### **3. An explanation for subways' inability to reduce congestion**

In analysing what has happened, the following conclusions can be drawn:

- The opening of the subway attracts many former mass transit passengers and just a few motorists;
- The transfer from mass transit reduces the demand for that mode and at least in the medium term, will reduce the flow of buses on the corridor, especially during rush hour, unless bus companies continue operating as they did before even with lower demand (this seems to have happened in Santiago);
- The road space freed up during peak hours is used by motorists who prior to the opening of the subway left a little earlier or a little later in order to avoid the worst congestion of rush hour. As a result, in the medium term, speeds at peak hours are about the same as they were before the subway came on line; and
- The few motorists who switch to the subway free up parking spaces, especially downtown, which are taken by other citizens switching from public transit to cars, though not necessarily on the axis of the recently opened subway.

In cases of very little use of private transportation, as was true 100 years ago, the situation could be different. The road space freed up by the shift mentioned in the second point would remain unused (without counting a small redistribution in time of trips on mass transit), which would nullify the consequence identified in the third point; the process identified in the fourth point would also be of little or no significance.

It is worth noting that the fact that subways do not reduce congestion during rush hour does not mean that they cannot be beneficial from a socioeconomic point of view. First, travel time is reduced for people switching from bus to subway; second, by making rush hour shorter, more citizens are able to travel at times that suit them better, rather than at times when there is less congestion.

### **4. Consequences of denser land use**

In the medium term, the subway's contribution to solving the congestion problem could actually be negative because of its impact on land use, influenced by building regulations adopted by many municipal authorities throughout Latin America. Undoubtedly, the subway improves access to areas near stations and therefore encourages greater residential and especially commercial density. That increased density does not always occur, as it also depends on other factors; it is likely to occur in neighbourhoods that are attractive from a city planning standpoint and is evident in districts such as Chacaíto in Caracas and Providencia in Santiago.

In these areas, the greater accessibility created by the subway leads to the construction of office buildings that workers can reach easily on subway trains. The regulations prevailing in many Latin American municipalities require, however, that these buildings have a minimum number of parking spaces per square metre of floorspace. This creates a perverse situation, in which many office workers, taking advantage of the parking spaces provided by municipal decree, do not use the subway but drive instead. In Santiago, the higher density of trips at peak hours within the subway's sphere of influence can be calculated (see table III.7).

Table III.7  
**TRIPS ON MODES OTHER THAN THE SUBWAY WITHIN THE SUBWAY'S  
 SPHERE OF INFLUENCE IN GREATER SANTIAGO, 1991**  
*(Trips in car equivalents per km<sup>2</sup> during morning rush hour)*

Mode of transportation	Density of trips in subway's sphere of influence	Density of trips in the city in general
Cars	816	492
Bus	206	122
Individual taxi	21	12
Collective taxi	33	14
	<b>1 076</b>	<b>640</b>

**Source:** Internal estimate made using basic data found in: i) survey of origins and destinations in Greater Santiago in 1991, conducted by the Interministerial Secretariat of Transport Planning, Santiago, Chile, ii) Catholic University of Chile (PUC) Institute of Economics (1993) and iii) various annual reports and telephone interviews at the Empresa de Transporte de Pasajeros Metro S.A., Santiago. The subway's sphere of influence is defined as a strip five blocks wide (equivalent to about 500 metres) surrounding the subway lines.

## 5. How can subways help reduce congestion?

The fact that subways have rarely reduced traffic congestion, at least since the beginning of the era of massive car use, does not mean this is impossible. The measures that would have to be taken to maximize their contribution in this regard include the following:

- When a new subway line begins operating, the supply of parking spaces in areas near stations should be reduced by the number of people switching from car to subway; and
- Municipal regulations governing parking at commercial buildings should be revised so that those built near subway stations should have a maximum limit rather than a minimum number of parking spaces per square metre.

Even if these measures are taken, the impact of the subway during rush hour would be limited by motorists' changing their travel schedules, which is impossible to control.

Subways are no doubt part of a number of measures aimed at improving the flow of traffic, which necessarily must include the availability of attractive mass transit systems. Subways are not enough by themselves to bring about a reduction in congestion, however.

## **I. ADVANTAGES AND DISADVANTAGES OF SUPPLY-SIDE MEASURES**

### **1. Advantages**

#### **(a) The measures achieve results**

Supply-side measures in general expand transport capacity, achieving a certain reduction in congestion. In some cases the effect on congestion is marked, as is the case with synchronization of traffic signals, segregated lanes for buses and reversible-flow lanes. Specifically, increases in the average speed of circulation and low travel times and operating costs are obtained.

#### **(b) Lower toxic gas emissions**

Higher travel speeds mean a reduction in total emissions of toxic gases, which helps improve the environment.

#### **(c) Savings in public transit fleet**

The higher travel speed of buses allows them to carry the same number of passengers in a smaller number of vehicles. This reduces the total cost of the fleet, with the resultant lower fares, which is of particular benefit to low-income travellers who must invest a major share of their income in transportation.

#### **(d) Greater social equity**

Along with lower fares, shorter travel time for buses improves their riders' quality of life, and most riders are in the social strata with the least power.

#### **(e) Some measures can be implemented at low to moderate cost**

Several supply-side measures are affordable for most municipalities in big cities. That is true of redesigned intersections, marking lanes and erecting signs and instituting reversible-flow lanes. Eventually, segregated lanes may be financed through franchising.

**(f) Retention of public transportation users**

The measures related to improving public transportation increase its attractiveness and reduce the pressure to switch to motor vehicles. To the extent that cities in developing regions manage to maintain the high proportion of trips still carried out on mass transit, which fluctuates between 50% and 80%, the most serious congestion problems can be avoided.

**(g) A quality public transit system discourages urban sprawl**

If public transportation is adequate, there are advantages to running businesses or living near its routes, which reduces the pressure to move to the suburbs where commuters depend on cars.

## **2. Disadvantages**

**(a) Some measures are costly**

Centralized synchronization of traffic signals, though highly effective, is costly. The same is true of the reorganization of public transit into a system equivalent to a surface subway. These projects may require financial support from the national government, which is also usually the case with subways.

**(b) Difficulties in adapting to reversible-flow lanes**

Reversible-flow lanes require that traffic flowing in the opposite direction be diverted. This may result in longer travel times and there may be a certain amount of congestion. The measure can cause confusion among drivers and an increase in accidents, so a solid signposting and publicity programme must be put in place. Some degree of resistance on the part of drivers should not be ruled out.

**(c) Problems with segregated lanes in the centre of the roadway**

Pedestrians must be given safe access to bus stops, and signs must be posted with instructions on how to cross lanes to the left.

**(d) Problems with segregated lanes at the side of the roadway**

The issue of making right turns and gaining access to properties located along the length of the roadway must be resolved.

**(e) Problems with the introduction of new technologies**

Centralized control of traffic signals requires a complex technology system that is available in few places. The reorganization of public transportation into a system similar to a surface subway also demands new



technologies for controlling traffic and possibly integrating fares with other bus lines, with the corresponding system of distributing revenues among the various players, plus some kind of smart ticket. The new technologies require training for those who are going to operate the systems, and passengers also must adapt.

**(f) Need to create new institutions**

A service similar to a surface subway needs a new set of institutions capable of running the complex system, in which various components come together (transport infrastructure and its relationship with the network of streets and roads, vehicles and their operation and control, ticket sales and the distribution of revenues, general management, public relations and others). The interests of all these institutions must be considered.

**(g) Resistance to change**

A service similar to a surface subway is a complex measure to implement, not only because of the difficulties inherent in installing a new system, but also because of the resistance to change that characterizes the players involved in the previous system. In particular, the reaction of bus companies, which may not be in a position to become integrated into the new arrangement, must also be taken into account, and it cannot be forgotten that passengers must also incorporate new practices in their travel.

## **J. ONGOING, CONSISTENT ADJUSTMENT OF SUPPLY**

Transport supply should be viewed as a system, and it must be improved and adapted constantly. Better results can be expected from the simultaneous and progressive intervention in a broad range of facets that make up the transportation system, such as the appropriate marking and maintenance of streets, the synchronization of traffic signals, the rationalization of public transit and many others. In other words, a number of feasible measures must be put into practice with a view to expanding capacity by improving the management and productivity of the existing infrastructure. Of all measures, the most promising ones seem to be the synchronization of traffic lights and the establishment of segregated bus lanes, along with the corresponding reorganization of public transit.

Improving and even widening streets is a potentially useful measure, provided that negative effects on habitability and quality of life can be avoided. In addition, it should be accompanied by others aimed at preventing the rapid clogging of these streets, or the mere shift of the congestion to a few blocks away. Simply adding more road infrastructure does not eliminate congestion,

however, and it is important to resist succumbing to the illusion that it can be solved with urban freeways, tunnels and viaducts. In fact, these measures may even exacerbate the situation. Experience shows that in Los Angeles and other major metropolitan areas that built numerous urban freeways, they were so attractive for cars that congestion became much more unmanageable.

In any case, improving the utilization of the supply does not by itself account for the complex realities associated with congestion. Urban motorways, especially in city centres, do not have sufficient capacity to support the indiscriminate use of private motor vehicles and they never will, even if all the financially, environmentally and politically feasible measures are taken to expand them. Thus, it is necessary to incorporate demand-side measures to resolve the imbalances in the use of the infrastructure and achieve a balance acceptable to the community.

## Chapter IV

### **CONTROLLING CONGESTION WITH DEMAND-SIDE ACTIONS**

#### **A. TRANSPORT DEMAND AND URBAN CONGESTION**

##### **1. What is transport demand?**

Transport demand is a response to the need or desire to transport persons and goods from one place to another. Activities take place in different places around the city, involving multiple trips to come and go, for example, from home to work or school, to go shopping, attend cultural, social, or recreational events, or others. To make better use of the day, many work and educational activities begin early in the morning, which results in a huge accumulation of journeys during relatively brief periods of time. This situation is repeated in the afternoon at the end of the workday, although it is generally less marked.

Although the essence of this demand is the mobilization of persons or things, it also has a traffic dimension, in terms of volumes of vehicles moving along the public roadways to carry out these objectives. The aforementioned concentrations of trips in the morning and afternoon generate an increase in the volume of traffic, known as peak times or rush hour, which translates into congestion on different streets and during different periods.

##### **2. Both supply-side and demand-side action is required**

Transport supply has been developing in response to demand and should continue to do so. Nevertheless, it should be acknowledged that the large number of cars and the marked preference for using them, aggravated by the fact that drivers do not fully appreciate the transport costs involved, make this effort insufficient on the whole.

Action must also be taken on demand. Problems become particularly apparent in downtown areas during rush hour and that is where the greatest efforts must be focused. Measures contributing to a lower volume of vehicles circulating in those places at those times, extending those periods, or encouraging people to plan journeys for before or after those times, are all useful. The alternative of completely eliminating a given number of trips would

be inappropriate insofar as it meant a loss of the advantages to be gained from such trips, along with the potential suppression of the activities people wish to carry out. In the medium and long terms, however, modern communication technologies such as Internet, email and mobile telephony, or the modification of land use can help reduce the need to travel, with the resultant easing of congestion.

Completely eliminating cars from city centres seems unviable and unnecessary.

Is it necessary to ban cars?

Demand-side measures should focus primarily on modifying the distribution of transportation modes or the type of vehicles used during peak times and on shifting some trips to times of lighter traffic. Using cars less during rush hour in fact expands the availability of roadway space, which translates into increased speeds and shorter travel times for all vehicles, obviously including public transit vehicles.

According to this reasoning, congestion could be cut significantly if it were possible to convince a large number of motorists to take mass transit or use non-motorized methods when they travel to heavily congested areas or go during periods of heavy congestion, or to change the times of their trips. In other words, it is a question of inducing changes in behaviour that would result in the temporary replacement of the car. The expected results are:

What behavioural changes would reduce congestion?

- Greater utilization of modes of transportation with a high occupancy coefficient, including carpooling;
- Shifting of car travel from peak hours to off-peak hours; and
- Travel on foot or by bicycle.

### 3. Demand-side measures that prevent congestion

There are many different demand-side actions that can be useful in easing congestion.

Several methods are aimed at changing driving habits by identifying convenient alternatives. These methods attempt to instill in motorists a strong conviction that will lead them to make lasting changes in behaviour, such as voluntarily restricting the use of the car (see section F.1 of this chapter).

Other methods are designed to induce changes in behaviour through coercion or incentives/disincentives. Coercive measures are regulatory in nature and they impose restrictions on drivers. Incentives, in contrast, provide advantages or economic rewards for those who adopt certain behaviours, and disincentives exact a price for engaging in certain activities (GTZ, 2001). Economic measures can seem less effective and in some cases are reputed to be socially inequitable, although they may enjoy more acceptance among drivers. Regulatory measures, on the other hand, are vulnerable. Both types of measure should be considered so that the best overall result can be obtained.

A variety of measures can contribute to the desired change in transportation habits to mitigate congestion. In this chapter, the following measures are described:

- Controlling on-street and off-street parking;
- Staggering or spreading out work, school and business schedules;
- Restricting the circulation of certain vehicles or prohibiting certain vehicles at certain times;
- Road pricing using electronic and non-electronic collection methods;
- Methods and situations that alleviate congestion by means of instilling personal convictions and reducing the need to travel.

In addition, the chapter presents reflections on the relationship between land use and congestion in the long run.

## **B. CONTROLLING PARKING**

Parking is obviously an indispensable element of any road transport system. Cars, in particular, are not designed for perpetual motion; they make certain specific trips, depending on the driver's intent. After the journey is completed, or after a sequence of journeys, when the driver no longer needs to travel, the vehicle rests in place, and it must necessarily occupy a space that is therefore eliminated from any alternative use.

This fact means that managing parking can be a tool for regulating transit and alleviating congestion. The presence or absence of parking spaces and the cost thereof, can facilitate or hinder access by car, especially on routes where the driver must find an accessible place to leave his car. A shortage of parking near a given destination or a high price for parking is in fact a disincentive for using private vehicles in many cases; and ample availability of parking has the reverse effect.

How can parking control alleviate congestion?

A better balance must be achieved between accessibility and limitations on the use of cars. This may mean that public transportation must be improved, or that restrictive measures must be implemented gradually.

### **1. Description of the measure**

Controlling parking consists of regulating the availability of parking places in various parts of the city with a view to relieving congestion. Controlling parking by restricting the number of spaces available or charging for their use has long been recognized as one of the most effective elements in any strategy for reducing car use (Enoch, 2002). In this way, the message is conveyed that not all car trips at all times are good for society.

One option for easing congestion is to discourage car trips to downtown areas during peak hours. Given that more than half of journeys at those times are for going to work, there is an interesting potential for attacking congestion through actions to discourage or hinder long-term parking in or near areas with a large concentration of workplaces. Restrictions can encourage commuters to switch to high occupancy vehicles or to shift their travel to off hours.

Relieving congestion by regulating parking can achieve the following objectives:

What does parking control aim to achieve?

- Freeing up space on streets and avenues for the circulation of vehicles, thus expanding the effective capacity of the roadways;
- Reducing car travel that results in long-term parking, such as commuting between home and work;
- Promoting the use of transport methods with a high occupancy coefficient, including carpooling;
- Encouraging drivers to make their trips during off hours instead of peak hours;
- Facilitating short-term parking for business, personal affairs and other uses in heavily congested areas;
- Cutting the time vehicles spend searching for a parking space.

Controlling parking in congested areas can take several different forms, including:

- Completely prohibiting parking in certain places at certain times;
- Establishing quotas for parking spaces or times; and
- Charging a fee for parking or for providing parking spaces.

Moreover, providing intermediate parking places to enable commuters to combine car travel with public transit can also help alleviate congestion.

It should be emphasized that controlling parking is not intended to prohibit the use of cars, much less to hamper the development of urban activities. Therefore, it is necessary to balance the appropriate provision of parking in uncongested areas with certain limitations on parking in congested areas, in order to achieve the best results for the development of a city.

The experiences of several different countries have shown that parking regulations and proper enforcement of them can yield positive results and can play an important role in reducing the use of private cars.

In any case, measures should be differentiated according to the type of parking, as shown below:

- Free or unrestricted on-street parking
- Regulated or paid on-street parking
- Paid off-street parking
- Free off-street parking

The possibilities for mitigating congestion using the aforementioned methods are discussed below.

## **2. Free or unrestricted on-street parking**

Drivers like to park on the street, since in many cases this is a reasonable solution near a specific destination, especially if it is free. Unfortunately, the space thus occupied is taken out of circulation for the entire time the vehicle remains there. This reduces the capacity of the street and can become critical on heavily traveled arteries, particularly at rush hour.

### **(a) Selective parking bans**

As the name suggests, this measure consists of banning parking at certain times and places.

The ban virtually rescues a lane for vehicles in circulation, at the cost of inconveniencing the relatively few vehicles that might be parked there. An additional lane can allow some 1500 vehicles to pass through each hour, greatly enhancing the flow of traffic on high-demand thoroughfares and drastically reducing congestion. The most noteworthy aspect is that this roadway space is already available and can be freed up with measures that transport authorities can readily implement.

The prohibition of on-street parking is justified only in areas where it can make an effective contribution. It is appropriate on streets where the volume of traffic is such that more space is needed to ease the flow. This is generally true of major avenues and streets in city centres.

The ban can be permanent on main avenues, on one or both sides; and it can be temporary on other streets, applicable only on workdays (Monday through Friday or Saturday morning), excluding nighttime hours. In contrast, it makes no sense to impose such a ban on neighbourhood streets.

One case that should be noted is stopping for loading and unloading, which should be banned at peak hours and expressly allowed during times when traffic is light.

This measure is generally taken at the municipal level and it can enjoy a reasonable degree of citizen support. The greatest resistance to implementing it may come from residents who do not have their own parking spaces; in that case, allowing nighttime parking should be considered where feasible.

### **(b) Banning parking is not enough**

As in so many other cases, it is not enough just to adopt the ban (OECD, 1981). The parking ban must be posted appropriately with conventional signs, and when the measure is adopted it must be widely publicized so that no one can plead ignorance. At any rate, it is preferable to win citizen support, since voluntary compliance makes it much easier to achieve the objectives. For that reason, explaining the goal of the measure is essential.

All things considered, the measure must be strictly enforced and

violations should result in real penalties. In this regard, it is important to have a mechanism in place, especially during times of peak demand, that will guarantee a high probability that violators will be discovered. This means having an appropriate number of inspectors and a good patrol system. In addition, an objective schedule of penalties and a good enforcement system must be adopted. Absent effective controls, illegal parking will abound. Provisions that do not have a working enforcement system soon become dead letter. In Washington, D.C., where parking regulations were flouted routinely, an enforcement system with wheel clamps and tow trucks met with initial resistance, but later it was accepted and the system was eventually privatized (MINTRATEL, 1995). A similar experience has been reported in Guatemala City.

To be successful, a parking ban must be part of a set of measures, among which improved public transportation should be considered. In addition, it is important to have parking places available in the areas surrounding the restricted zones so that those who want or need to go there by car will have somewhere to park.

### **3. Regulated or paid on-street parking**

If a ban is justified on heavily travelled streets, on many other streets where parking is allowed, it should be regulated by means of metres and other methods of rationalizing demand. The purpose is to make it likely that a space will be found when needed and if parking has to be paid for, to make the driver assume the cost to society of providing the space.

In city centres, on-street parking should be short-term. This allows access for personal business or shopping and prevents parking by commuters, who are the ones most likely to be travelling at rush hour.

Payment of a fee should be the primary method of rationalizing regulated on-street parking and it provides the added advantage of generating revenues for the municipality. It may be appropriate to set maximum limits on parking time, although charging a fee is itself a deterrent to long stays. A less stringent regulation is to allow free parking that is severely limited in time, which would ensure rotation. Another method is to reserve spaces for national or foreign dignitaries' vehicles, although that could be considered discriminatory and might meet with resistance. No matter what method is used, appropriate signs and symbols should be posted at the location to convey the restrictions clearly.

Regulating on-street parking is generally a municipal function and it may enjoy reasonable public support. The cost of implementation is normally affordable with funding from the municipal budget or franchising, and costs can be offset by fees.



**(a) Parking metres and other forms of limiting stays**

There are different ways of implementing controls. A simple option for limiting time, regardless of whether the on-street parking is paid or free, is to use a standardized document displayed visibly within the vehicle that indicates the authorized parking time. The sale of parking permits for specific periods is one such measure. Improvements in technology have reduced the vulnerability that originally characterized these systems.

Parking metres are effective ways to regulate authorized on-street parking. These devices have a wide range of features (they can be simple clocks, or they may have mechanical or electronic means of collecting fees manually or automatically, in the form of coins or cards). It is preferable for the metres to be able to limit the total time vehicles are allowed to remain parked.

In countries with low-cost labour or high rates of unemployment, it is possible to operate parking systems with human collectors equipped with devices that can record parking time. In addition to creating sources of formal employment, this method makes it possible to charge for the exact time of use, without the need for a minimum fee for parking. As a result, non-payment for time exceeding the prepaid amount can be avoided. Moreover, the collector is in fact an enforcement officer and the use of informal “vehicle watchers” can thus be eliminated.

Franchising the parking metre operation has the advantage of reducing the risks inherent in the business, especially with respect to collecting fees. It also avoids the expansion of the municipal payroll. Another similar option is to establish a decentralized city-owned corporation.

**Box IV.1**

**PARKING MEASURES HELP REDUCE UNEMPLOYMENT  
AND CONGESTION IN SANTIAGO**

A number of municipal jurisdictions in Santiago, Chile have contracted with businesses to carry out on-street parking enforcement using human collectors equipped with hand-held electronic meters that can also issue a receipt for the driver. During times of high unemployment, this measure has resulted not only in a successful regulation of the supply of on-street parking, but it has also created formal jobs.

In addition, about 4,400 underground parking spaces have been built, eliminating 5,500 parking spaces on the street. A law passed in 1997 authorized municipalities to grant concessions on the subsoil of their jurisdictions as a means of clearing the streets and reducing pollution. The concessions are granted after approval by the Ministry of Housing and City Planning (MINVU) and require the elimination of surface parking spaces amounting to at least 120% of the authorized underground spaces. In the area surrounding the new parking structure (200 to 500 metres away), on-street parking is prohibited in order to increase the space available for circulation and also prevent competition with nearby parking.

**Source:** Law 19,495 of Chile and the newspaper *El Mercurio*, Santiago, 25 May 2001.

**(b) How much to charge?**

Charging a fee for a scarce good in high demand is a mechanism aimed at ensuring that drivers pay the costs incurred by society, and no less than the true cost should be paid. Furthermore, the fee should be whatever is necessary to rationalize use in accordance with demand, which means that it may be a fixed amount or one that varies by time of day.

The fee charged for on-street parking should cover:

What is paid for using a parking space?

- The costs of adapting the location for parking (signposting and equipment) and operating the parking system, including, of course, the salaries of workers and inspectors, in order to self-finance and eventually franchise the system. To the extent that this does not occur (as is sometimes the case), drivers will receive an implicit subsidy, with the consequent overuse;
- The value of the right to occupy public space for a period of time; this can be calculated on the basis of the costs that congestion imposes on vehicles in circulation because they do not have the full width of the pavement available to them (Valenzuela and Gálvez, 1995). In other words, without parking, a certain speed of travel prevails, with the commensurate level of consumption, whereas with parking spaces on the street, these factors are different; the parking fee can be calculated as the difference between the two, which can give rise to differential fees throughout the day.

In addition, it is recommended that parking metre rates be higher than the fees charged for underground parking so as to encourage the latter, since it is preferable to take parked vehicles off the street.

**(c) Effective control is needed**

Human collectors can be the first line of defence in a control system, and they should be complemented by a group of supervisors. In the case of direct payment to parking metres, inspectors should be assigned (one inspector for every 100 to 150 spaces) to prevent non-payment. There is no doubt that franchising the parking metre business is the most effective collection system.

An important element in the proper functioning of on-street parking is consistent enforcement in a given area. If metred parking spaces are adequately patrolled and nearby areas where parking is banned are not patrolled, there will be a great risk of illegal parking.

**(d) Prohibiting the use of regulated parking spaces during peak hours**

Prohibiting the use of regulated parking spaces during the morning rush hour is one way of expanding efforts to alleviate congestion. This measure serves

the purpose of facilitating the flow of traffic and prevents commuter parking. Drivers who would otherwise park there must change their mode of transportation or travel during off hours, thus easing the heaviest flows of traffic.

If current parking concessions are affected by this measure, appropriate compensation must be considered.

#### **4. Paid off-street parking**

It is logical that most parking will be off-street, either on private lots or on public land off of the pavement. Not only is it impossible for the streets to provide enough room for all vehicles to park, their primary function is not parking.

Paid off-street parking can be underground, in parking structures, or above ground. Sometimes above-ground parking is set up haphazardly on vacant lots; from a city planning standpoint, it would be a good idea to require the upgrading of such lots. One aspect that merits attention is access, as entrances and exits should not be a source of congestion; any queuing that results should take place outside the lanes of the main thoroughfare.

Off-street parking has the advantage of reducing pressure for on-street parking and can be a commercial business venture. High-rise or underground parking structures involve huge investments, but they can be profitable with the collection of fees. They may be the result of private initiative or the concession of surface space (on public land off the street) or the public subsoil (under avenues, plazas, parks and other properties, for example). High-investment concessions tend to go hand in hand with the prohibition of parking on all streets within a certain radius of blocks to prevent the erosion of demand.

How the concession is structured, including what agency grants the concession, depends on each country's institutions. These concessions may or may not fall within the purview of the municipal government. Drivers accustomed to parking at low cost may express a certain amount of resistance.

Box IV.2

**LONG-TERM PARKING RESTRICTIONS**

In Munich, Germany, a comprehensive parking policy was adopted for the entire city, with flexible fees depending on the occupancy level. An important line of action was to eliminate 1,200 long-term downtown public parking spaces (operated by franchises or by the municipal government) in order to raise the price of private long-term parking. Large stores have limited parking and it is expensive; moreover, like service centres, stores must develop their own access to public transit stations. At the same time, actions were taken to expand mass transit capability and improve the mix of vehicles on public roadways, curbing the aggressiveness of car drivers through “traffic calming” measures on the streets.

In Paris, France, the number of long-term parking spaces was also limited in the city centre by eliminating 3,500 spaces. Parking fees were raised and a unified fare system was implemented for parking and mass transit. The capacity of the beltway was also improved, with an underground motorway built on the south/southeast stretch.

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**Source:** Ministry of Transport and Telecommunications (MINTRATEL), “Análisis de la problemática de estacionamiento en las principales ciudades del país”, study prepared by Consultores en Ingeniería de Transporte Ltda. (CITRA), Santiago, Chile, June 1995.

**(a) Payment as a regulatory tool**

Paid off-street parking can also play a role in controlling congestion. Of course it allows for the elimination of on-street parking.

Payment is also an incentive for rationalizing the use of the car, especially in the case of long-term parking. It must be noted that it is feasible to charge municipal fees, either for using public land or for operating a business, in order to bring rates to appropriate levels.

**(b) Prohibiting paid off-street parking**

A complementary method of reducing the availability of long-term parking would be to prohibit entry into paid parking areas during morning rush hour. This would require paying compensation to parking companies for lost revenues. Initial indications are that it is more appropriate to levy a tax so that the amount of the parking fee would discourage commuters from leaving their cars parked for an entire workday.

Box IV.3  
**PARKING REGULATION STUDY IN LONDON**

A 1998 study analysed various measures for easing congestion in London, including several proposals related to parking. One was to raise the fee for short-term parking in the city centre. It was estimated that a 200% hike would reduce traffic by 4%; for reasons of equity, parking fees in other commercial areas competing with downtown businesses would be raised as well.

Another proposal was to raise long-term public parking rates by 200%, which would reduce traffic by 6%. The imposition of a 5,000-pound yearly tax on every private non-residential (PNR) parking space would stem traffic flows by 13%. The effect would be most notable in the outer reaches of the city, where a large number of such spaces are currently available at low rates.

The study called for the gradual implementation of the fee increases, as shown below:

	2000	2003	2005	2008
Public parking	+20%	+50%	+100%	+200%
Annual PNR rate	-	£ 1 500	£ 3 000	£ 5 000

**Source:** London Planning Advisory Committee (LPAC), "Developing Road Traffic Reduction Targets of London", study carried out by Halcrow Fox, London, December 1998.

## 5. Free off-street parking

Various institutions offer free parking to enhance their operations. Bearing in mind at all times that the problem is most acute in city centres during rush hour, the institutions can be classified based on their impact on congestion, as indicated below:

### (a) Shopping centres, service institutions and for-profit businesses

Providing free parking for customers may be a vital necessity for the functioning of shopping centres and other entities where the public goes to conduct transactions or business, such as medical centres, payment offices for utilities, banks and various public and private enterprises. Individuals may stay a short time at these locations, and much of their business (though not necessarily the majority) is conducted during off hours anyway.

Along with having appropriately designed entrances and exits, in congested areas it may be possible for these entities to be closed for business at the height of the morning rush hour. Except for medical establishments, it may be feasible to regulate business hours in this manner with a view to eliminating or limiting service during peak traffic times. Any other type of restriction, such as charging a fee proportional to the establishment's surface area, would meet with great resistance and might inhibit the development of businesses and institutions in the area in question.

**(b) Workplaces and centres of higher learning**

Company-provided employee parking is a different matter, since travel to workplaces occurs primarily during rush hour. These perquisites may be offered to attract qualified employees or may be the subject of collective bargaining agreements. Free student parking provided by institutions of higher learning has a similar effect.

One byproduct is that parking facilities at schools and workplaces stimulate urban sprawl, since they make it possible to live in places not served by public transit. Furthermore, public may never reach these low-density residential areas. Thus, car-dependency is increased, with an even greater impact on congestion. Urban sprawl also increases the cost of running the city because basic service networks must expand outward and travel distances and costs grow accordingly.

A complete ban on entry during the morning rush hour may be an unviable and overly drastic alternative for alleviating congestion. A more feasible option would be to charge the entity in question a fee or tax for every parking space provided. This cost could be passed on to students, but not to employees. Another option is to limit the number of parking spaces that can be provided, obviously to less than the number of employees. In both cases, if public transportation is deemed inadequate, the establishment can provide collective transportation or encourage carpooling. It can also try to introduce flexible work or class schedules so that not everyone arrives at the same time.

This type of regulation affects property rights, so it cannot be introduced by a municipality on its own; an ordinance authorizing the restrictions may be required. These measures would undoubtedly meet with strong opposition in the entities in question.

Box IV.4

**PAYING COMMUTERS TO LEAVE THEIR CARS AT HOME**

A number of English companies are paying their employees to give up the right to park on company property. The hospitals in Derriford and Southampton, Heathrow Airport, the telecommunications firms Orange in Bristol and Vodafone in Newbury and the pharmaceutical company Pfizer's plants in Kent and Reigate all have plans to implement this measure. They are applying different schemes, ranging from a single "expropriation" fee for the right to park, to daily compensation payments, to annual or monthly payments to workers who arrive at work by any means other than a car. The daily payments fluctuate from two to five pounds and the monthly payments are in the range of 80 pounds. This measure suits the companies' interests, as it is much more expensive for them to provide parking spaces, particularly if they decide to expand their facilities or move to another site.

The most successful schemes have been the most flexible ones, involving a payment for every day the parking is not utilized; more than one-third of the employees agree to leave their cars at home under such circumstances. The downside is that these plans are more costly to administer. In contrast, few employees have been interested in the schemes for longer terms. The programme could be even more effective if the income from these payments were tax-exempt. Complementary actions that have been helpful are establishing minibus routes, subsidizing the use of public transit, facilities for cyclists and a carpooling database.

In Santa Monica, California, a state law was passed in 1992 requiring companies with more than 50 employees located on the southern coast of the state to offer employees who are eligible for free or subsidized parking a bonus for declining to use it. The law also applies to leased off-site parking, and the bonus must be equal to the amount previously charged for parking. A 1998 law made these payments tax-exempt for employers and employees alike. Employees may reject the offer and continue to use the company parking, or accept it and travel by other means or park at their own expense. This measure has been useful for reducing traffic and emissions.

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**Source:** M. Enoch, "UK parking cash out experience and lessons from California", *Traffic Engineering + Control (TEC)*, vol. 43, No. 5, London, May 2002.

**c) Parking at residential developments**

Parking at residential developments is indispensable, and there must be enough space so that vehicles are not parked on the street. Steps must also be taken, however, to design entrances and exits in a way that prevents traffic jams.

## 6. Intermediary parking

Another possibility for easing congestion stems from the combined use of cars in uncongested areas and public transportation on the rest of the journey. This allows the car to be used only on the part of the route where the costs to the driver are not significantly different from the costs to society. One prerequisite for this solution is to provide intermediary parking facilities. The travel scheme would be as follows (OECD, 1981):

- Travel by private car in outlying areas, where there is little or no public transit, for example, because any fares collected would not pay for the cost of serving remote areas with low occupancy rates;
- Car parks outside the city centre near a public transit station or stop; and
- Utilization of some form of public transportation to reach the city centre, with appropriate and reliable service, hopefully faster than travelling by private car, so as to obviate the need to find parking downtown.

The success of an intermediary parking system depends on various factors, as indicated below (OECD, 1981):

- They must be located near high quality public transit lines that operate at adequate frequencies and speed and offer comfortable seats and sufficient capacity;
- They must be clearly accessible, even by those not familiar with the road network;
- Their entry and exit capacity must be sufficient during peak hours;
- There must be a high likelihood of finding a free space, as lengthy searches may cause the driver on his way to work to continue the journey by car;
- The foot path from the parking area to the public transit station should be short and, if possible, covered;
- Parking fees and public transit fares should compare favorably with the cost of making the entire journey by car;
- The driver must be assured that his vehicle will not be at risk for theft or vandalism; and
- The intermediary parking system must be advertised in promotional campaigns, and signs pointing to the car park should be posted on the roadway.



Box IV.5

**INTERMEDIARY PARKING IN THE UNITED STATES**

Intermediary parking has been established in many urban areas in the United States, including Baltimore, Boston, Hartford, Portland, Seattle and Washington, D.C.

The Baltimore region has seven free car parks for a total of 1,770 spaces, served by express or local bus lines. Intermediary car parks in the Boston region are linked to rapid transit lines (express bus or train) for commuting to work.

The Hartford and Portland regions have numerous intermediary car parks. In Hartford there are about 30 parks with express bus service and another 84 established for carpooling. In Portland there are 73 free car parks served by mass transit. The TriMet, the mass transit authority, does not own any of these car parks, but makes use of parking spaces made available free by churches, shopping centres and suburban municipalities.

Seattle has six permanent intermediary car parks owned by the transit system and 15 part-time parks provided by shopping centres or churches. All of them offer free parking and are served by mass transit lines.

Washington, D.C. has three intermediary stations with bus service and six located near subway stations. A fee is charged for parking.

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**Source:** Organization for Economic Cooperation and Development (OECD), *Evaluación de sistemas de estacionamiento*, Madrid, Grupo de Investigación Vial, 1981.

## **7. Advantages and disadvantages of controlling parking**

Controlling parking is one of many tools available for combating vehicular congestion. The advantages and disadvantages it entails are discussed briefly below:

### **(a) Advantages**

#### *Some improvement achieved*

Whether parking is prohibited, the private cost of parking at various facilities is raised, or shuttling between car and public transit is facilitated, a certain improvement in congestion is achieved on principal avenues and in city centres by freeing up space on the roadway for the flow of traffic. Moreover, during peak hours travelers shift from cars to public transit or put off their trips until off hours. The results include higher average travel speeds, with the consequent reductions in travel time and operating costs. These results have been observed in many cities that have applied the measure.

#### *Lower toxic gas emissions*

Higher travel speeds reduce total toxic gas emissions, which helps improve the environment.

#### *Costs of implementation*

The costs of implementing a ban on parking are relatively low—informing the public, posting signs, patrolling and enforcing—unless businesses with contractual rights must be compensated, as is the case with parking concessions that lose business during certain hours.

If parking structures have to be built, the costs may be moderate for surface structures, but very high for underground or high-rise structures. The advantage is that they can be privately financed by granting concessions.

#### *Congestion costs assumed by those who cause it*

Charging for parking is a reflection of the sound economic principle that the costs imposed on society should be defrayed, be they for implementation, for land allocated to parking, or for congestion caused directly by the reduced available road surface or indirectly by rush hour car travel.

#### *Message limiting urban sprawl*

Restricting parking in downtown areas during peak hours sends a positive message that tends to limit explosive urban development. Indeed, if it is difficult or impossible to find parking when driving to work, the use of public transportation has to be accepted, or the employee must live relatively close to the workplace, which will dampen the urge to move to the suburbs for more than a few people. A more compact city pays lower costs for urban development, transportation and utilities.

### **(b) Disadvantages**

#### *Conflicts with customs and desires*

People have a strong desire to travel by car and parking restrictions make that difficult, especially during rush hour. This can cause a certain amount of resistance. The more extensive the measure, the greater the resistance, especially if companies and businesses see access to their facilities threatened. Opposition can also come from municipal authorities, for the same reason.

What factors arouse resistance to parking controls?

*Problems for residents in restricted parking areas must be solved*

Residents of an area where parking is restricted must have access to their homes, so a system must be designed to make that possible. Outsiders may take undue advantage of that access, however.

*Loss of rights*

To the extent that businesses lose acquired rights, they must be compensated in the amount of the damage. For example, a commercial venture or a franchisee may lose revenue from parking fees when parking restrictions are imposed.

*Death of downtown?*

Radical parking restrictions, especially downtown, can threaten the area's vitality. Throughout the city there must be reasonably appropriate parking spaces for the development of various activities. The design of parking facilities must ensure that i) there is access to the city centre; ii) activities are not hampered in areas with restricted parking; and iii) the quality of the ambient area is maintained. Unfortunately, the results of studies and models developed to date are not conclusive with regard to the magnitude of the impact that parking limitations may have on business and commercial activity and employment in the city centre. Since there appears to be some correlation, however, complementary measures should always be adopted for a commensurate enhancement of public transportation (Still and Simmonds, 2000).

## **C. FLEX TIME**

Traffic has definite peak periods when large numbers of trips are made. This phenomenon is generally attributable to the fact that at the beginning of the day there is a lot of activity, causing many people to travel nearly simultaneously to work or school. A similar phenomenon, though less marked, occurs in the afternoon when the work and business day ends. Consequently, congestion can be relieved to the extent that it is feasible to spread the start time of different schedules over a longer period.

### **1. Description of the measure**

Flex time involves establishing different starting and ending times for the various activities that go on in large cities, such as work, business, school, college and the like, so that each activity begins at a different time than the others.

What does flex time consist of?

The purpose of this measure is to avoid very definite peak times by staggering journeys over a longer period of time. In this manner, the time of greatest demand for the roadway system is spread out and the streets are less congested. Obviously, the best results are obtained when rush hour trips are distributed over a longer period time.

The reorganization of schedules depends directly on the nature of activities in each city; in any case, care should be taken not to interfere with the normal functioning of the activities subject to modification. Every city has different business activities, an educational system that may or may not have evenly staggered schedules and a culture that may or may not facilitate the application of this measure.

There is a tendency for schools to start earlier than most jobs, since parents like to be able to drop off their children on the way to work. Higher education, business and most private activities can be scheduled more flexibly.

What changes and adaptations are feasible?

One definite option is to have different starting times for work in different sectors, such as the public sector, the private sector, banking and construction. Sometimes this occurs spontaneously, as construction tends to begin as soon as the sun rises. The public sector, in turn, can start earlier or later, depending on national idiosyncrasies or the number of hours offices are open—if they are open for six hours, it is feasible to schedule the entire workday before lunch. Bank customers can conduct their business on the Internet, so there is no need for banks to open early.

Another possibility is to encourage businesses to allow employees to work flexible hours wherever feasible. In other words, each employee would choose his own times for arriving and departing, as long as the required number of hours is worked and they are present when all employees are needed for meetings or other joint activities. Telecommuting, taking advantage of modern communications technology, the Internet, email and other innovations, can also help spread out schedules. In any event, it must be acknowledged that the private sector lends itself better to such creative solutions.

Some case studies demonstrate the validity of flex time as a means of reducing congestion (Fernandes, 1985).

## 2. Specific cases

During the Second World War, Philadelphia and other U.S. cities pioneered the implementation of staggered schedules to ease the demand for public transportation to business centres during peak hours.

Several U.S. cities, as well as Toronto and Ottawa (Canada) and Paris (France) have implemented programmes that have been positively evaluated from various points of view, such as reducing the number of rush hour trips, cutting travel times and greater comfort on public transportation (Fernandes, 1985).

Numerous businesses in developed countries, including some public agencies, have flexible work hours that each employee chooses voluntarily, the only condition being that all employees must be at the workplace during specified hours. Many workers do indeed elect to travel to during off hours, either before or after the morning rush hour.

Several Brazilian cities have adopted flex time plans, including Rio de Janeiro, São Paulo, Porto Alegre, Recife and Curitiba. The results are a smaller number of trips during peak hours, less fuel consumption and increased travel speeds for public transit vehicles (Fernandes, 1985).

In Guatemala City, the start of the public sector workday (including municipal offices) was delayed till 9:00 a.m. in 1996. Since schools begin at 7:00 a.m., the measure had a significant impact on congestion.

In Santiago, Chile, schedules have gradually been staggered, in some cases spontaneously. Hence, construction begins at approximately 7:00 a.m., factories at 8:00 a.m., schools between 8:00 and 8:30 a.m., public agencies at 8:30 a.m., banks at 9:00 a.m., the private sector between 9:00 and 9:30 a.m. and retail businesses from 9:30 a.m. onward. Banks have mandatory business hours and a few decades ago retail businesses were required to open at 10:00 a.m. Once the latter were allowed to open when they chose, they began their day slightly earlier, as shoppers do not tend to go out early in the morning.

Furthermore, a complication is arising in Santiago: publicly funded schools are in the process of switching from a split session (different groups of students attend class either in the morning or in the afternoon) to a joint session, so many students who used to travel in the afternoon before rush hour will now be going to school in the morning, with the consequent overloading of public transportation. A study (MIDEPLAN, 1998b) has identified this impact on the urban transportation system. One line of action proposed to counteract it is to have staggered schedules at different schools to avoid the pressure of many additional trips during rush hour.

### 3. Advantages and disadvantages

#### (a) Advantages

##### *The measure yields certain results*

It is obvious that it does result in a longer period of time when people are traveling and therefore less traffic during the heaviest times, which means shorter travel times and lower vehicular operating costs.

Does flex time have a real impact?

##### *Low implementation costs*

The measure itself does not cost any significant amount to implement, although there may be costs stemming from the need to adjust to new schedules.

#### *Possibility of maintaining habits*

Commuters have the option of continuing to travel at the times they prefer.

#### *Savings in public transit fleet*

A longer rush hour means that the same total number of passengers can be moved with fewer buses and therefore the density of trips is reduced.

### **(b) Disadvantages**

#### *Costs of adjusting to new schedules*

The required adjustment to new schedules could result in temporary productivity losses.

#### *More trips due to changes in schedule*

Additional trips may be required, because the staggering could hinder a combination of trips that was previously feasible. That is typical of parents taking their children to school and continuing on to work, which may not be possible without immediately returning home.

#### *Change in habits*

Changing habits is at least a subjective inconvenience, as it entails rearranging activities. It takes time to arrive at a new system.

#### *Difficult measure to implement*

In the private sector, the authorities have little chance of mandating a certain schedule of activities.

## **D. RESTRICTING VEHICLES**

Given that congestion occurs because many cars are circulating, it has occurred to some that congestion could be eased by prohibiting a portion of the existing fleet of vehicles from circulating, without infringing on the right to buy vehicles.

### **1. Description of the measure**

Vehicle restriction involves prohibiting the circulation of some vehicles during certain periods in certain areas, Monday through Friday. This measure has been applied to reduce congestion or environmental pollution; therefore, depending on the intended goal, the type of application will vary. The focus here is to deal with congestion by taking a certain number of vehicles out of circulation in the restricted area, although in contrast there are references to controlling pollution.

What is vehicle restriction?

**(a) Who should be restricted?**

Obtaining appreciable results in cutting congestion requires prohibiting a significant portion of the fleet, which should rotate throughout the week. Usually the measure is applied to 20% of the vehicles subject to restriction each day Monday through Friday, although this proportion may be higher when pollution indices are high.

The prohibition may encompass all vehicles across the board, or some may be exempt. Private vehicles (meaning cars, all kinds of taxis, pickup trucks and vans) are the main ones affected.

What types of vehicles would be restricted?

Furthermore, it is common to ban the circulation of trucks and other freight vehicles in downtown areas during rush hour and to establish special times for loading and unloading.

It makes no sense to prohibit the circulation of buses unless the goal is to combat pollution as well, since it is buses that cause the least congestion per passenger transported and that provide an important option for those who must leave their cars at home. For this reason, school transportation, which is done by minibus in many cities, should not be affected either. Collective taxis do not transport enough passengers to justify exemption, and if they were exempt, there would be tremendous pressure to convert individual taxis into collective ones en masse.

**(b) Ways of imposing the restriction**

One simple option is to go by the last digit of the licence plate. A daily ban on two digits would restrict 20% and allow all vehicles to be covered between Monday and Friday. Other formulas allow a greater or smaller fraction to be restricted. It is a good idea to keep the same rotation pattern over a long period of time, possibly several months, as frequent changes cause confusion among drivers. If the pattern remains in place for too long, however, it penalizes those who are restricted on Friday, when many people wish to leave the city. Therefore, the pattern should change every so often.

Another, more market-oriented possibility is to discriminate by circulation permit or travel fee. In cities where this measure is to be implemented, an additional fee would be charged, which would be higher for those who wish to be exempt from any restriction, a lesser amount for those who wish to be restricted one or two days a week, for example, and nil for those restricted Monday through Friday. The fees would be set at levels that would cut circulation by the desired amount. Vehicles would be distinguished by windshield stickers of different colours and characteristics. To be sure, the opposite could be done, that is, reducing the cost of the annual permit by different amounts depending on how many days a week the restriction is to be in effect. In any event, it must be accepted that enforcement is more complicated than it is when the final digit of the licence plate is the criterion.

### **(c) Restricted districts**

This measure should cover all districts of the city where there is congestion. That is generally true of the city centre and various major avenues. The restriction should be limited to these areas, although for reasons of practicality and simplicity most of the city tends to be affected within an established perimeter. Applying the restriction to the entire city is only justified for environmental reasons.

### **(d) Periods of application**

The restriction should be in force during periods of congestion, meaning rush hour, especially in the morning. If many drivers choose to go to work by different means, it is less likely that they will be using their cars in the afternoon rush hour, which would automatically alleviate congestion.

The restriction has been applied for the entire day, excluding the nighttime hours. Imposing it during valley or off-peak hours during the day would be justified by environmental reasons, not congestion.

On holidays and during the season when urban traffic diminishes significantly because of vacations, the vehicle restriction should obviously be suspended.

## **2. Effectiveness of the restriction**

There is no doubt that prohibiting circulation can have an impact on traffic volumes in the short term, as it effectively shrinks the size of the fleet of vehicles.

How effective is the restriction?

In the medium term, however, its impact diminishes. The high rate of vehicle purchases observed in Latin America over the last decade means that in three or four years the number of vehicles may grow by 20%, cancelling out the effects the restriction is intended to achieve. Additional pressure on the growth and, incidentally, on the ageing of the fleet comes from the fact that those who can afford it have an incentive to buy a second vehicle, possibly an older one, to evade the restriction, especially if it applies to whole days.

## **3. Examples of application**

Restricting vehicles as a means of combating congestion was tried in Buenos Aires, Argentina in the 1970s, when half of all vehicles were prevented from entering the city centre depending on whether the last digit of the licence plate was even or odd. The method was also used in Caracas, Venezuela in the 1980s.

The same prohibition was imposed on half of all vehicles in Athens, Greece between 1985 and 1991. Assessment of the programme did not yield



good results, as the fleet grew older when many drivers purchased a second vehicle. Moreover, the circulation of motorbikes increased, and it has been shown that they cause more pollution than cars. Compliance with the restrictions also declined over time (MINTRATEL, 1995).

In Managua, Nicaragua, half of the fleet of taxis has been subject to restrictions since 2001, when the excessive number of vehicles in circulation caused congestion. Vehicles with even-numbered licence plates circulate between 6:00 a.m. and 2:00 p.m., while those with uneven numbers may do so between 2:00 and 10:00 p.m.<sup>1</sup>

Another example of this measure, taken for the purpose of combating air pollution, is in Mexico City, where there is a permanent vehicle restriction programme. From Monday through Friday, between 5:00 a.m. and 10:00 p.m., vehicles are prohibited from circulating according to the final two digits of the licence plate, with each vehicle being allowed to circulate one day a week. On days when pollution indices are high, the restriction is applied to half of all vehicles (even or odd licence numbers). Studies show that the negative impacts of this measure are higher than the positive ones. One reason is that people have bought second vehicles, so in effect many individuals are not restricted at all. Indirect evidence suggests that environmental pollution has grown worse because of the restriction (Tovar, 1995).

Box IV.6

**VARIOUS INITIATIVES RESTRICTING CARS AND FAVOURING  
ALTERNATIVES IN BOGOTÁ**

In Bogotá, Colombia, the programme called “Pico y placa” [peak and plate] has been in place since 1998. It consists of restricting four licence plate digits per day from Monday through Friday, only during peak hours of the morning (7:00 to 10:30 a.m.) and afternoon (5:30 to 7:30 p.m.). The speed of traffic has increased by 43%, fuel consumption has fallen 8%, and air pollution is down 11%.

It should be noted that several other steps are being taken to promote travel on foot (restoring sidewalks, which often have been invaded by parked cars) and by bicycle (with a network of bike lanes). In addition, a public transportation network with high-capacity buses travelling on special roads, known as Transmilenio, has been put in place.

In addition, measures have been adopted to encourage people not to drive private cars. For seven hours every Sunday, 150 kilometres of roads are closed to vehicle traffic so that they can become bicycle-only roads. The first Thursday in February, between 6:30 a.m. and 7:30 p.m., “car-free day” is celebrated. As the name suggests, on this day people are invited to leave their cars at home, and it has enjoyed widespread acceptance.

**Source:** A. Hernández, “Bogotá, una ciudad vivible”, ([http://www.cepal.org/Transporte/noticias/8/9178/Bogot\\_viv.doc](http://www.cepal.org/Transporte/noticias/8/9178/Bogot_viv.doc)), March 2002.

<sup>1</sup> Newspaper *La Prensa* of Managua, 17 November 2000.

Box VI.7  
**A CITIZEN PROJECT IN SÃO PAULO**

Since 1995, a number of experiments in restricting vehicles have been conducted in the metropolitan region of São Paulo, Brazil. At first, voluntary vehicle restriction was practised for a week; then the State Secretariat of the Environment suggested that each day cars with a certain combination of final digits on the licence plate be left at home. The first two days, participation was relatively high at 50%, but it fell in the ensuing days. The overall average was 38%.

In 1996, the restriction became mandatory (State Law 9,358) and a fine of 100 reales was levied against violators. This plan was in place from 5 to 30 August, between 7:00 a.m. and 8:00 p.m. Compliance with the measure hovered around 95%. It is estimated that during the period when the law was in force, carbon monoxide emissions fell by 1,171 tons and 40 million litres of fuel was saved. The average speed of traffic rose by 20% and congestion during peak hours was cut by 40%.

Between 23 June and 30 September 1997, the plan was again put into effect between 7:00 a.m. and 8:00 p.m. throughout the São Paulo metropolitan area, with a fine of 78.16 reales levied against violators. Compliance was relatively high at 90% in the morning and 85% in the afternoon. During that period, carbon monoxide emissions fell by 42,460 tons, particulate matter by 200 tons.

After October 1997, the restriction was applied only in the city centre, during the morning and afternoon rush hours (7:00 to 10:00 a.m. and 5:00 to 8:00 p.m., respectively). Studies on the effectiveness of the measure, carried out between October 1997 and May 1998, concluded the following:

- Congestion was reduced by 18% between 7:00 a.m. and 8:00 p.m.
- The reduction in congestion was 37% in the morning rush hour and 26% in the afternoon;
- Average speed on a busy city street used as a point of reference increased by 23% in the morning rush hour and 24% in the afternoon;
- The benefit from the programme was estimated at US \$2.57 million per day of operation, of which 78% corresponded to savings in time and 10% to reduced fuel consumption.

This initiative has been promoted and adopted as a citizen project, in which everyone makes a contribution to easing congestion.

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**Source:** Information provided by Eduardo Vasconcellos, *Associação Nacional de Transportes Públicos* (ANTP), Brazil.

Box IV.8

**VEHICLE RESTRICTION FOR ENVIRONMENTAL REASONS IN SANTIAGO**

Vehicle restrictions have been in place since 1986 in Santiago, Chile, for the stated purpose of decreasing environmental pollution caused by motor vehicle emissions. Pollution is most serious during the coldest period of the year (April to August) because the lack of wind hinders the dispersal of pollutants. In recent years, however, the measure has been in place from March to December, which has shown its usefulness in reducing congestion as well.

The restriction is in effect from 6:30 a.m. to 8:30 p.m. throughout the city and adjacent areas Monday through Friday, with light vehicles being taken out of circulation according to the final digits of their licence plates, two digits being affected each day according to a table that is changed every few months. Within the perimeter of the beltway avenue, freight vehicles are also subject to the same restrictions. When pollution climbs higher than acceptable levels, exceptional measures designated “alert”, “pre-emergency” and “emergency” are triggered. One consequence of these measures is that the number of licence plate digits subject to restrictions is increased to four, five and eight, respectively; certain avenues are also limited to buses only in order to help them travel more rapidly and thus reduce their emissions.

Originally, the restriction applied only to vehicles without catalytic converters, as a means of encouraging the purchase of vehicles equipped with them and thus enhancing air quality. This measure has stimulated the conversion of the vehicle fleet to those emitting fewer pollutants. Since 2001, however, 20% and 40% of vehicles with converters, respectively, have been restricted during pre-emergency and emergency states. The rationale for this measure is that although they pollute less, they still contribute to pollution, especially by raising dust on the streets. Vehicles with catalytic converters are identified by means of a green windshield sticker and those without them have red stickers.

**Source:** Atmospheric Decontamination and Prevention Plan for the Metropolitan Region of Santiago, Chile, Supreme Decrees 16 of 1998 and 20 of 2001.

#### 4. Advantages and disadvantages

##### (a) Advantages

*It is effective in the short term*

Cities applying this measure have reduced congestion in the short term, but the effect dissipates because of the expansion of the fleet of vehicles and the possible purchase of a second car. If the measure is applied with a variable-cost additional circulation permit, it is easier to make incremental changes in the number of vehicles allowed to circulate. As long as congestion is eased, travel times will decrease and average speeds will therefore increase.

A real but passing effect

#### *Less pollution*

This impact is seen in the short term as traffic levels decline.

#### *Low implementation costs*

This measure requires publicity and, above all, enforcement, generally by traffic authorities.

### **(b) Disadvantages**

#### *Expropriation of drivers' vested rights*

Vehicle restriction, either by licence number or by surcharge, involves the dilemma of infringing upon the right to travel, which has been paid for expressly each year. Suspending this right during certain pre-established periods amounts to an expropriation and can give rise to constitutional and legal arguments. In some countries, a law may have to be passed to allow this measure to be put in effect. Chile's case is emblematic, as the measure has officially been implemented on environmental grounds, even though many interpret it as an anti-congestion effort.

#### *Difficult to enforce*

In view of the heavy volume of traffic during peak hours, enforcement is difficult, especially if stopping a vehicle causes more congestion. That might cause people to flout the restriction, which would be against equity.

#### *Additional expansion and ageing of fleet in the medium term*

This occurs whenever it is possible to obtain a second or even a third vehicle, at low cost, of course, to evade the restriction.

## **E. ROAD PRICING**

Traffic congestion is partly due to a strong propensity to drive, reinforced by the fact that individuals do not perceive the cost imposed on others when they drive under those conditions. Road pricing is one way of ensuring that those who cause the added costs pay for them, so that only those who are willing to pay the price are allowed to continue circulating during peak hours. This contributes to a net reduction in traffic.

## **1. Description of the measure**

Road pricing consists of levying a fee to circulate in or enter specific streets or areas during times when there is congestion there. The purpose is to make individuals circulating in a congested area see that their presence there imposes a cost on the other vehicles circulating in the area, in the form of longer travel times and higher operating costs, especially fuel costs (see chapter II). Normally this additional cost is not internalized individually, and drivers' decisions are made according to a vision of the cost to themselves; and even if they take into account the effect that congestion has on them, it is less than the total impact.

The result is that traffic increases more than is good for the economy. In practice, the perceived price of driving in a congested area is analogous to a subsidy, without any economic reason for it.

On the contrary, to the extent that each driver internalizes the added cost he imposes, the use of public roadways is rationalized. In fact, certain drivers will not be willing to pay the price of congestion and will seek out other alternatives, either using other modes of transportation or driving at times when the fee is not charged.

In theory, road use would be optimized if the exact additional cost could be charged at all times (known as the marginal cost in technical terms) and if people knew that value for each one of their travel options before beginning their journey. The result would be the control of congestion.

Consequently, charging a fee for congestion is a disincentive for using personal vehicles in congested areas and times. It is interesting to note that this regulates the use of public roadways by means of a market tool rather than a regulation imposed by the authorities.

The application of this measure entails various decisions, as discussed below:

### **(a) Which areas or streets should be subject to pricing**

Ideally, pricing should be applied to every stretch of roadway affected by congestion and only there. It makes no economic sense to apply pricing elsewhere, which would be contrary to the overall public welfare. The problem is that there are not yet adequate cost and effectiveness technologies for this purpose, although in the Netherlands and the United Kingdom there is an effort to develop them (see box IV.8).

In practice, currently available technologies limit the application of road pricing to specific areas or streets. In the first variant, the fee is charged for entering areas defined as congested or for circulating on any street within them; in the second, it is charged for travelling on individual streets deemed congested. To avoid arbitrariness, the characteristics that must prevail in order for a place to be considered congested and for streets and areas to be subject to pricing must be defined and publicized.

The problem with these schemes lies in the physical or temporal margins of the areas subject to fees. It is easy to imagine that nearby streets, though not designed for it, will have heavier than normal traffic and may even become congested, with an increased risk of accidents. The same thing would happen immediately before or after the pricing period. This would transfer at least part of the congestion to places or times that were free of pricing.

**(b) When pricing should be in effect**

Pricing should cover periods when there is congestion, which generally happens during rush hour. The morning rush hour tends to be the most congested, so it is possible that the measure will be sufficiently effective if applied only during that time; many people would stop driving to work, which would automatically relieve the afternoon rush hour. If the congestion lasts beyond rush hour, pricing could extend beyond it as well.

**(c) Which types of vehicles should be subject to pricing**

It would apparently be necessary to subject all vehicles to pricing, because they all contribute to congestion, albeit at different levels. The main causes of congestion, however, in terms of the number of passengers carried, are cars, so it is acceptable to apply the measure to them alone.

**(d) How much should be charged**

Fees can be levied in accordance with the distance travelled, the time spent on the street, the amount of congestion in the area or street in question, or simply for entering them. The socially optimum fee is equal to the additional costs the vehicle entering the flow imposes on others already circulating there. Technically, that would entail increasing the private costs of circulating on the congested street until they are equal to the social costs.

What should be considered when setting congestion fees?

Since the amount of congestion varies over time, even within rush hour, strictly speaking the fee would have to be variable, with the consequent system of informing drivers so that they could take it into account at any time. Without ruling out the possibility that the technology for making this theoretical system a reality may someday exist, at present we must be content with setting fees that reflect as well as possible the congestion created and letting everyone know in advance what they are so that no one feels deceived. This is a scenario known as the “second best” option.

**(e) What technology should be used for collecting fees**

Technologies for collecting fees have improved dramatically in recent years. There are several fee collection systems available for urban streets these days. They can be classified as follows:

### *Manual system*

This consists essentially of using a card attached to vehicles' windshields if drivers wish to circulate in the areas subject to pricing. The cards can be purchased at various outlets. The cost of implementing this system is moderate, although it has the drawback of a potentially high rate of evasion; moreover, it requires a lot of enforcement personnel, as visual inspection must occur at many different points, with the practical problem of effectively recording all violations.

Payment at stations similar to traditional toll booths is unacceptable in urban areas, as it would cause heavy congestion at collection points.

### *Electronic system*

In the electronic system, the fee is automatically charged as each vehicle passes through the area in question. For this purpose, each vehicle must be equipped with a transponder or tag, which sends a signal to antennae located at collection points (Pérez, 2001). There are basically two types:

- A transponder that identifies the user; the fee is collected by sending a bill periodically to the party, or it is deducted from an account previously identified by the party. This system is also known as "second generation fee collection", in contrast to collection at traditional booths. It has the drawback of identifying at what time the driver passed through a given place, which could be considered an invasion of privacy.
- A transponder that includes a pre-paid card, with the corresponding amount being deducted from the value of the card at each point. This is also known as "third generation fee collection". Although it is true that this is a more complex technology, it protects the identity of the driver, as long as the card included in the transponder has a high enough balance.

To work properly, electronic systems must include several subsystems, such as the following:

- Detection and classification of vehicles: they must be capable of identifying vehicles subject to payment and those exempt from payment; they must also be able to handle several lanes of traffic simultaneously, or else traffic must be channeled into separate lanes in a timely fashion;
- Warnings to drivers that they are approaching a collection point;
- Actual collection of the fee;
- Identification of violators: normally this is done by taking a photograph of the licence plate of the suspect vehicle (as it does not have a transponder or enough of a balance on the card, or some other defect);
- Antenna-transponder and antenna-central computer communication;
- Administration, including billing or charging and reporting of violators.

Box IV.9

**POSSIBLE FUTURE COLLECTION SYSTEM**

In the Netherlands and the United Kingdom recently, experts have cited the need to develop a system for collecting, on any route at any time, the costs that each vehicle imposes by circulating, including congestion costs.

Briefly, the idea consists of requiring every vehicle to be equipped with a unit that makes it possible to locate the vehicle at all times no matter where it is using Global Positioning System (GPS) technology. Monitoring is done by satellite. The system would enable authorities to locate vehicles on all roads, be they large or small, urban or rural. The portion of the fee corresponding to circulation, compared to that corresponding to congestion, would vary according to the type of street and the volume of traffic on it; on most routes the fee would be zero, as it would be on main roads during periods of light traffic.

Two possible methods of collecting the fee are under consideration, both similar to the electronic systems described above.

This possible future system is more equitable, since it would allow fees to be collected on all roads, thus solving the problem of what happens at the margins of times and areas subject to pricing. Advocates of the plan also propose keeping the fiscal revenues from the transport system constant, which means that if it is implemented, it would be necessary to cut fuel taxes and fees for circulation permits accordingly.

**Source:** Journal *World Highways/Routes du Monde*, April 2002 and *Road Pricing* Project, Netherlands.

## 2. Expected results of pricing

If a fee is charged for circulating on congested urban roadways, the following principal results can be expected:

What results can be expected from pricing?

- Changes in the mode of transportation, time and route of various trips, which would translate into less congestion; in any event, it is necessary to verify that negative impacts, such as congestion at times and places not subject to pricing, do not occur, thereby diminishing to some degree the benefits achieved;
- Reduction in the resources consumed for urban transport (vehicle operating costs and travel times);
- Less emission of pollutants;
- Less stress because of decreased travel time and traffic jams; and
- Generation of revenues from congestion fees, which could be used for various purposes such as an urban transport fund, improved road maintenance, better public transportation and others.



### 3. Matters to resolve

Road pricing has been under discussion for more than three decades, but there are not many instances of its application. It is clear that

What possible impacts should be studied preventively?

the population and legislators are highly resistant to this measure. There are various reasons for the resistance, including doubts about the real effects, the fairness of its application and the effectiveness of enforcement; fears about the impact on the development of areas subject to pricing and about discrepancies in the use of the revenues collected; opposition to new taxes and other arguments. It is not insignificant that no city except Singapore has implemented road pricing specifically to control congestion. Singapore has many characteristics that make it a special case, such as the fact that it is an island nation, that it has a government with extensive powers and that its population accepts a large number of regulations in all aspects of life.

For that reason, before trying to introduce road pricing, the following factors should be considered at a minimum:

- The impact on alternate routes to those subject to pricing, many of which will be local streets not necessarily designed to handle heavy volumes of diverted traffic;
- The existence of appropriate public transit options to replace private cars;
- Residents' access to the area subject to pricing;
- Possible adverse impact on low-income disadvantaged persons who travel by car;
- Business, retail and educational activities in the areas subject to pricing; these must be considered early in the process of planning and all interested parties should participate in the identification of possible solutions. One possibility to bear in mind is staggering the schedules of such activities;
- The allocation of revenues: there is strong resistance to new taxes, so the only spending that the public is apparently willing to accept is for improved public transit, investment in widening, rehabilitating, maintaining, marking and posting signs on streets, promoting development of the city and the like, but they would be unlikely to tolerate pouring the revenues into the general fund of the nation; and
- Lack of understanding of collection technologies.

To the extent that these factors receive adequate consideration, it may be possible to gradually increase public acceptance. At any rate, an extensive information and persuasion campaign cannot be omitted.

#### 4. Examples of application

Numerous studies of road pricing have been conducted in different cities around the world since the 1960s, but actual applications are few. Until the middle of 1994, the only application of road pricing to control congestion was in Singapore, which introduced its programme in 1975. The measure was intended to alleviate congestion, but the fees are very high. Thus, it can be inferred that collecting revenues is an essential objective of the system.

Congestion is under control in Singapore, especially since fee collection was automated. At first the system was manual, but now it is electronic. Thus, it is possible to vary fees in order to prevent a concentration of trips just before or after the period when the highest fee comes into effect.

Road pricing was tested in Hong Kong and officials finally decided not to implement it. One of the main reasons for this was the technology used; it recorded the location of every vehicle at every moment, which was considered an unacceptable invasion of drivers' privacy. Moreover, fees were to be collected by mailing a bill and it was feared that there would be a high number of errors. It can be concluded from this experience that choosing the technology for fee collection is a very important decision, since one that is not trusted or accepted sufficiently by the public may cause the measure to fail.

Box IV.10

##### CHARGING URBAN TOLLS IN NORWAY

The Norwegian cities Oslo, Bergen and Trondheim charge tolls on avenues leading into the city centre. The initial objective was to collect funds to invest in urban transport, especially roadwork. In the city of Trondheim, plans are under way to improve the fee collection system both in space and in time, in order to vary the rates according to time and place. Although the objective of the road pricing in Trondheim is still to collect revenues, differentiating the rates by time of day, with greater amounts charged during periods of high demand, brings the plan in line with the concept of road pricing to control congestion. In this case, for drivers who pay electronically, entering the city centre between 6:00 and 10:00 a.m. costs from 25% to 50% more than between 10:00 a.m. and 5:00 p.m. No fee is charged at other times.

Urban tolls in Norway are an interesting experience from the standpoint of manipulating demand. There was a decline in the number of car trips. In Trondheim, a 10% reduction was observed during toll periods and an 8% increase was seen during free periods, which suggests shifts in travel schedules. Surveys also show that many people have switched to buses.

**Source:** Wirtschaftswissenschaftliches Zentrum der Universität Basel (WWZ), *The Use of Economic Instruments in Urban Travel Management*, documents from a joint conference held by OECD, ECMT (European Conference of Ministers of Transport), GVF (Dienst für Gesamtverkehrsfragen de Suiza) y NFP (Nationales Forschungsprogramm Stadt und Verkehr de Suiza), Basel, 1992; and European Good Practice Information Service, "Traffic-efficient Trondheim. Road Pricing - The Toll Ring of Trondheim/Norway, *Local Sustainability* (<http://www3.iclei.org/egpis/fgpc-154.html>), 2003.

In addition, studies have been done for the city of Santiago, Chile, using the ESTRAUS Model (see chapter V). It is not likely, however, that Congress will pass the law allowing the fees to be charged.

Box IV.11  
**ROAD PRICING IN LONDON**

More road pricing studies have been conducted in the United Kingdom than in any other country, yet to date no system has been put into place. This situation may change in 2003.

Ken Livingstone, mayor of London, ordered a toll of five pounds to be collected each day, beginning 17 February 2003, from all those entering the city centre of London Monday through Friday between 7:00 a.m. and 6:30 p.m. by crossing a pre-defined cordon of streets. This measure was something he had promised during his election campaign. Opponents of the measure have lobbied intensively, but the courts rejected their lawsuit attempting to have it annulled.

A study on anti-congestion measures in London (LPAC, 1998) concluded that road pricing applied within a specific area in the city centre would be an appropriate mechanism for cutting traffic in that area. Decreases of 8%, 32% and 48% could be achieved with tolls of 2, 5 and 10 pounds, respectively. These figures seem high, and in practice, traffic is expected to decline between 10% and 15% in the centre once the agreed-upon measure has been applied. Outside the cordon, however, the impact would be limited, since many journeys begin and end without going into the centre.

Revenues ranging from 130 million to 180 million pounds per year are expected, and will be used for improving public transit. The system will be implemented by selling entry permits at authorized locations. Every ticket sold will be entered in a database along with the licence number of the vehicle it pertains to. Cameras placed around the perimeter of the area will automatically record the licence numbers of vehicles crossing the cordon and they will be compared with the database for verification.

**Source:** London Planning Advisory Committee (LPAC), "Developing Road Traffic Reduction Targets for London", study conducted by Halcrow Fox, London, December 1998; and *The Guardian* (<http://www.guardian.co.uk/transport/Story/0,2763,519544,00.html>), 14 February 2003.

## 5. Advantages and disadvantages

### (a) Advantages

*The measure appears to be effective*

Although there is not much empirical evidence, the measure appears to have yielded significant results, reducing the number of car trips during rush hour and transferring a certain proportion of them to public transportation. At least this is what the model studies show, particularly the one conducted for Santiago.

Does road pricing achieve results?

With fewer vehicles circulating, travel times are reduced, traffic speeds rise, and the cost of operating a vehicle declines.

It should be noted that these effects are probably short-term, and the results may be different in the medium and long terms.

*Lower toxic gas emissions*

With fewer vehicles on the road travelling faster and stopping less often, pollution diminishes.

*Internalization of congestion costs by those who cause it*

Road pricing corrects the economic distortion that arises when drivers do not perceive the costs that they impose on others by causing congestion and allows for the rationalization of the transportation market. Instead of the authorities imposing regulations, the use of public thoroughfares is regulated by market mechanisms.

*Possible source of revenues for projects*

The revenues generated by this measure are considerable, and they can be used for projects to improve urban transit or for local development.

**(b) Disadvantages**

*Difficulties applying economic theory in practice (1)*

Collecting a congestion fee is intended to make the cost perceived by drivers equal to the social cost of using the public roadways, including the price others must pay for the resultant congestion, and thus to make vehicle use appropriate from a social point of view.

In theory, the price of the congestion caused, which varies tremendously, should be collected on every street in every location at every moment and should be known to all drivers at all times. This means that the number of streets subject to pricing and the amounts charged would be changing constantly. It would require a detailed monitoring of traffic on practically every block of every street and a dynamic calculation of the costs of congestion, which would be transmitted instantaneously to drivers as the corresponding fee was being collected. Current technology does not allow for this possibility, so road pricing is just an approximation, a “second best” choice.

*Difficulties applying economic theory in practice (2) and long-term effects*

Even if at some point it became possible to charge each vehicle for the additional or marginal costs it imposes on society, it is not clear what results road pricing would yield in the long run, since other components related to the transportation system are not governed by marginal prices. That is true of green areas and farmlands surrounding cities. Absent this type of pricing, or alternatively, controls on land use, cities will tend to expand, which complicates sustainability over the long term (see also section G.3 below).

#### *Increase in congestion in areas and times surrounding those of toll collection*

Drivers will tend to avoid going into streets or areas subject to fees, diverting traffic towards toll-free streets and possibly causing congestion there. Furthermore, immediately before a period of fee collection or higher fees, drivers will hurry to enter the area and risk causing accidents.

#### *Effectiveness of enforcement*

Because of practical difficulties with enforcement, manual systems have a high potential for evasion, which gives rise to inequity.

Electronic collection systems are more effective, although their current margin of error could undermine confidence if incorrect charges are made. To prevent such a reaction, the companies collecting road tolls using this technology usually prefer forgoing the fee in cases of doubt. In addition, in second-generation systems, the time and place of travel are recorded, which could spur resistance due to the invasion of privacy this entails.

#### *Implementation and operating costs*

The manual system has a relatively high cost, the electronic system an extremely high one. Nonetheless, revenues could cover these costs and generate surpluses. In this regard, the main problem of the electronic system is financing the hefty initial investment.

#### *Driver resistance*

Even if enacted, the measure may encounter strong resistance from drivers, who would have to pay more or leave their cars at home for some habitual journeys, with the ensuing loss of satisfaction, safety and reliability.

#### *Residents' access to toll zones, property values*

A solution must be found for people who live in toll zones; if they are charged a fee, they could be prompted to move, and if they are exempt, third parties might fraudulently take advantage of the system. Moreover, the effect on property values is not clear a priori.

#### *Problems with introducing new technologies*

Except for the manual system, introducing road pricing involves introducing a complex, cutting-edge technology that is still being developed. This poses a major additional difficulty.

#### *Need to create institutions to manage the system*

Road pricing, whether manual or electronic, is a complex system that entails collecting large amounts of money, which means that an entity to administer it must be created. That may be a company or other appropriate body, either a public agency or a private firm operating under licence. In any case, adequate controls must be put in place.

## F. EASING CONGESTION ON THE BASIS OF PERSONAL CONVICTION AND REDUCING THE NEED TO TRAVEL

### 1. Personalized travel planning

Recognizing that cars are extremely attractive because of the advantages they offer, a variety of methods have been developed and applied in some locations in an effort to encourage drivers to voluntarily change their car-related behaviours based on moral convictions. These methods rely on the notion that people are more likely to make changes if they are given goals that are consistent with their scale of values or that represent positive changes in their lives (Department for Transport, United Kingdom, 2002a and b).

Emphasis is placed on identifying personalized options for making necessary trips by means other than the single-occupant car. In the process, possible alternatives are analysed, and the advantages that individuals and society can obtain from them are examined. The idea is that changes in behaviour come about if their benefits are understood.

These methods are people-oriented, and therefore they represent a substantial, diversified effort. The results have been varied, but they offer hope for lasting behavioural changes. A summary of the methods used, together with an evaluation of each, can be found in Department for Transport, United Kingdom (2002a). In this study, the methods are categorized as follows:

- Those that offer assistance in identifying the best way to carry out specific journeys, either by car or, preferably, by public transit. Commuting to work is the main focus, although in some areas trips made for other purposes, such as looking for work or going to the hospital or convention centre, are included as well.
- Those that attempt to modify travel habits and attitudes. Some have been registered as intellectual property, such as IndiMark™, TravelSmart™, Travel Blending™ and Living Neighbourhoods™. IndiMark™ and TravelSmart™ are based on direct marketing in homes or by mail or telephone to promote the use of public transit and methods other than the car. Travel Blending™ and Living Neighbourhoods™ are carried out at the community or neighbourhood level, and involve detailed analyses of travel habits and ways of modifying them. Living Neighbourhoods™ applies Travel Blending™ in conjunction with other measures adopted by the locations in question to facilitate change.
- Miscellaneous methods, including strict management of parking at private entities (see the box in section B.5.b titled **“Paying commuters to leave their cars at home”**); driver education in schools; publicity campaigns designed to raise awareness of sustainable modes of transportation, health, the environment and others; and travel information offices.

Box IV.12  
**TRAVEL BLENDING™, A TOOL FOR CHANGING  
TRANSPORT BEHAVIOUR**

Travel Blending™ is a technique intended to rationalize the use of the car without changing people's activity patterns. In this sequence of procedures, families' habitual trips are recorded, then recommendations of possible changes are made, personal decisions are made about changes that are feasible and beneficial, follow-up and observation take place, and a final assessment is conducted. The desired result is that certain transport behaviours are modified.

The technique requires the participation of specialized advisers who can make appropriate recommendations for thinking about and organizing trips in advance, harmonizing modes of transportation, and harmonizing activities (in terms of time and place so that long trips are avoided). It is most appropriate in communities that share similar activities, such as businesses, neighbourhoods and schools. Although from this point of view it covers only partial groups, its effect on peak travel times can be significant. The table below sums up the results of three experiments.

**Travel Blending™ application results**

	Adelaide (Australia) (percentages)	Nottingham (England) (percentages)	Santiago (Chile)* (percentages)
Participants only			
Total number of trips made by driver	-22.7	-7.6	-25.4
Distance travelled for all trips reported (km)	-21.3	-14.2	-34.5
Total time spent travelling by car (hours)	26.2	-11.8	-26.7
Combined effect for participants and non-participants			
Total number of trips made by driver	-13.6	-3.3	-16.9
Distance travelled for all trips reported (km)	-11.2	-6.2	-23.3
Total time spent travelling by car (hours)	-19.3	-4.8	-17.0

**Source:** G. Hutt, "Travel Blending<sup>MR</sup>, una herramienta para el cambio de conducta en transporte", *Tranvía*, N° 18, (<http://www.revistatranvia.cl/tv18>), July 2002.

\* The area of application was relatively small, so it can be considered only a sample.

The emphasis on promoting voluntary behavioural changes is relatively new, and it should be acknowledged that, in Latin America and possibly in many developing countries, making it a reality may be difficult. Nonetheless, in developed countries such as Australia, this method is expected to cut car use by approximately 10% (*The Review*, 2002).

## **2. Driver education**

The behaviour of those who use the public roadways, be they drivers or pedestrians, has varying degrees of influence on congestion and also on safety.

The steady growth of roadway use led, first of all, to the establishment of rules of play, traffic regulations or standards, with a view to defining rights and restrictions on the use of streets and thus improving the flow of traffic as well as preventing accidents. Unfortunately, many people are unaware of these rules or choose to ignore them.

A lack of driving discipline or consideration for others in fact reduces the capacity of the road network to a fraction of its potential. Trying to gain a few seconds by violating the rules governing traffic at intersections or on streets seriously disrupts other vehicles' movement, translating into heavier congestion and, unfortunately, a greater risk of accidents. Pedestrians must also obey the rules of the road, crossing streets only at the times and places designated for that purpose.

Driver and pedestrian behaviour absolutely must improve. That is why it is so very important to educate the entire population on traffic rules from early childhood onward.

This effort has tremendous possibilities and a broad scope. Examples include driver education in school curricula, educational campaigns in radio and television spots or advertisements directed towards the public at large, driving schools, the requirement that a certain number of hours of supervised driving practice be carried out before obtaining a licence, and more stringent driving exams. Some noteworthy initiatives have been launched in Brazil, such as using mimes to teach people how to cross the street at designated locations and playing folk or popular songs that teach the rules of the road at places where crowds congregate. Another interesting innovation in Chile involves setting up uniformed student patrols to show classmates how to travel properly on the streets when going to and from school.

Immediate results cannot be expected, of course, but because young people are so malleable, programmes oriented towards them show great promise for future changes towards safer and more law-abiding behaviours.

## **3. Modern communication technologies**

Advances in computer technology make it possible to explore measures to encourage a reduction in the number of trips deemed necessary.

Beginning in the last decade of the twentieth century, residential access to the Internet and cable television has proliferated. This will certainly influence the timing and frequency of travel. An Internet connection allows greater flexibility in scheduling travel to work, and may also replace some trips with telecommuting. As a result, the concentration of demand at peak times can be diluted. In addition, some shopping trips can be replaced by ordering goods



online to be delivered by truck. It is also logical to assume that there will be less propensity to go out of the house for recreation, thanks to the expanded possibilities for at-home entertainment (Thomson, 2002a).

It is still premature to predict the repercussions of these changes, which are largely spontaneous in nature. In any event, support for this trend can be one way of reducing the demand for travel during rush hour.

## **G. CONGESTION AND LAND USE**

### **1. Long-term trends**

The spread of home ownership and car use has led to a deconcentration of residences and businesses in cities. In the past, only members of the aristocracy could afford to travel in private vehicles such as carriages, and consequently no one else could live or travel more than 10 blocks from a streetcar, train or bus line for school, work or recreation. This fact is still reflected in the cities of today. In Santiago, for instance, 1992 data from the National Institute of Statistics (INE) show that the population density in traditional neighbourhoods that were developed before the days of the car hovers around 10,000 persons per square kilometre, while in newer areas, generally located on the outskirts of the city, this figure is 2,000 to 4,000. In that same city, population density rose steadily from 1940 to 1980, but then it began to drop (Armijo, 2000) as citizens gained new freedom to travel by buying cars.

Between 1950 and 1970, in the U.S. cities of Chicago, Washington, D.C. and Boston, which by then were totally car-oriented, demographic density in the city centre had begun to decline as residents moved to the suburbs. Meanwhile, the opposite was happening in the centres of Latin American cities. Buenos Aires was the exception, as car driving arrived relatively early compared to the rest of Latin America, and it had the only suburban train system in the region, making it possible to live anywhere in a broad suburban area and commute downtown every day (Ingram and Carroll, 1978). Suburbanization is also made easier by the fact that in Australian and North American city centres, there are between 0.4 and 0.5 parking places for every job (Kenworthy and Laube, 1999).

There is a strong correlation between urban density and the cost of public transport per passenger-kilometre, which prompts a pernicious spiral of greater car use, deteriorating public transit, reinforced car dependence, and finally, a city that is unsustainable in the long term.

### **2. Availability of time to travel**

Several authors have identified parameters in the trips made by individuals that appear to remain rather stable across time in a single city and even in groups of cities. For example, the time spent travelling, per person and per

day, fluctuates between 45 minutes and approximately one hour and 25 minutes, with a marked concentration at about one hour. This is true whether the person lives in the United States or an African village (Schafer, 2000).

The speed of the available modes of transportation varies considerably. Thus, in the villages of Ghana, people cover only 3.5 kilometres per day in their daily hour, whereas in the United States they cover more than 60 kilometres, as they can travel by car rather than on foot. A study of data compiled between 1955 and 1970 in U.S. cities concluded that "daily travel time per traveller is notably similar" (Zahavi, 1976). If this correlation is true, a reduction in traffic speeds resulting from congestion would reduce the average distance travelled per person, unless alternative modes of transportation are found. Possible options are:

- A reduction in the average duration of journeys;
- A reduction in the frequency of journeys, perhaps accompanied by a greater use of various forms of telecommunications (Thomson, 2002a);
- A spatial shift of travel from more congested to less congested areas;
- A modal shift of travel from cars to relatively congestion-free modes, such as subways or motorcycles; and
- A temporal shift of travel towards less congested times.

Some of these effects have an impact on land use, but not always in the same way, so the net impact varies from one city to another. For example, reducing time available for travel would create a greater demand to live near workplaces or pressure to create new jobs near residential neighbourhoods; this would become especially apparent in cities with relatively strict land use regulations, particularly along the perimeter of the metropolitan zone, as is the case in Europe. In Latin America, where these regulations are looser, the opposite trend would occur; that is, residences and workplaces would move to outlying areas that right now are free of major congestion.

Traffic congestion can encourage the use of public transport modes that are at least partially immune to its consequences, that is, those operating on separate roadways. To the extent that their use increases, the demand for both residential and commercial property with good access would rise, as is the case near subway stations. Although this trend appears to be occurring in several cities in the region, in Latin America the modal distribution (the manner in which travel is spread out among different modes of transportation) seems relatively inflexible in the face of changes in the prices or travel times of the various modes (Swait and Eskeland, 1995).

In São Paulo, which is known for its heavy traffic congestion, surveys of travel patterns have been carried out over a period of 30 years. As a result, certain inferences can be drawn with respect to the influence of congestion and its possible impact on land use, though no definite conclusions can be reached. From 1977 to 1997, there was a reduction in the daily travel time per person from 76 to 64 minutes. Although there are no consistent figures on

traffic circulation speeds in São Paulo, they probably did decrease during this period; average speed per trip rose, however, from 9.4 km/h in 1977 to 9.7 km/h in 1987 and 10.9 km/h in 1997. The consequence is that, despite the reduction in time spent travelling, the number of kilometres travelled per person per day has remained stable. Moreover, the number of trips made per person per day fell from 1.53 in 1977 to 1.21 in 1997, and the average distance per trip rose from 7.8 to 9.5 kilometres (Companhia do Metropolitano de São Paulo, 1977, 1987 and 1997).

The situation has been analysed, at least partially, in relation to transport, but without identifying the impact of congestion on land use (Henry and Hubert, 2000 and Thomson, 2002a). The scenario is consistent with growing congestion, however, and this encourages the movement of residential areas towards the suburbs, forcing citizens to cover ever-greater distances between home and work. The greater physical separation and the rise in congestion, and perhaps also a greater availability of home entertainment thanks to cable television, causes people to make fewer trips. Heavier congestion is compatible with a higher average speed per trip if people switch from slower modes of transportation, such as ordinary buses, to other less slow modes, such as buses on segregated lanes, subways or cars; and this is what appears to have happened. From 1977 to 1997, the proportion of trips made by train (including the subway) climbed from 4.9% to 7.5%, and that of car trips from 26.3% to 30.9%. Trips made by bus fell from 40.1% to 25.8%, and in general, travel speeds seem to have diminished. The creation of separate bus lanes or streets in the most heavily travelled corridors during this time may have benefited more bus passengers, however.

### **3. Road pricing and land use**

Road pricing has been proposed as a means of improving the flow of traffic, cutting car use and promoting public transportation, and in general, of making the city a more enjoyable and sustainable place. The long-term effects of this measure, however, may be diametrically opposed.

A number of analysts have studied, usually with mathematical models, the effect of road pricing aimed at controlling congestion on the physical boundaries of the city. They have not always reached the same conclusions. For example, one study concluded that road pricing would reduce the demand for travel and that it would lead to a more compact city (Oron et al, 1973). Another reached the opposite conclusion (Mills, 1967). Particularly in Latin America, signs point to the conclusion that road pricing would cause greater urban sprawl.

Road pricing raises the relative price of driving a car in more congested areas, that is, in areas of greater residential or commercial density, which normally tend to be located in the city centre. In view of this increase, in the short term motorists tend to choose among three options, none of which is to their liking: i) switching to public transit; ii) continuing to travel by car but

during toll-free times, either by getting up early or by arriving at work later; or iii) continuing to drive as usual, paying the corresponding fee. The effect is that they have less access to areas subject to road pricing, making these less attractive places in which to live or work.

In the more distant future, drivers would have the option of moving away from the toll zone looking for cheaper places in which to drive. Since car owners tend to have relatively high income, their exodus would reduce the demand for both high-end residences and business or office complexes. Property prices could fall, and a process of urban decay might ensue.

Officials might try to halt this trend by improving the quality of public transit in the toll zone. Proposals for road pricing often feature such improvements and call for financing them with some of the toll revenues. The result would be better access to downtown areas for public transit riders. Regrettably, it appears that there is a very low tendency to switch to public transportation in Latin America; at least that was reflected in a study conducted for São Paulo (Swait and Eskeland, 1995)<sup>2</sup>. In other words, improvements in public transportation would not attract a large number of motorists, and their riders would generally remain persons of lower incomes and skill levels.

Especially in Latin America, business decisions regarding the location of offices take into account the preference of the most specialized employees, who are critical to success. Given that they usually travel by car and they must be kept happy to avoid losing them, they will probably have their road tolls reimbursed. No matter who is footing the bill, the costs of remaining in or moving to areas subject to road pricing would increase, and there would be pressure to go to exempt areas. Residents would also contribute to that trend if they are not exempt from paying tolls.

The new destinations might have a lower quality of public transportation than the city centre. Therefore, even employees who used to commute on public transit would have incentives to start driving, and if there is ample parking, that is exactly what they would do. New residents might also continue driving their cars without any surcharge being imposed on them. The result would be: i) less use of public transit; ii) more use of cars; iii) a tendency towards decay in the city centre; and iv) urban sprawl as the city incorporates land that had been devoted to farming or had been in a natural state.

It is difficult to avoid the conclusion that, unless the marked preference for driving cars could be changed, introducing road pricing in Latin American cities would lead to greater urban sprawl, the movement of workplaces out of toll zones and a reinforcement of the tendency of higher-income families to live in the suburbs, where public transportation is sometimes not very viable. The average length of trips would increase and the city would become more dependent on private transportation (Thomson, 2002b). The toll zone itself

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<sup>2</sup> The study found that elasticities in demand for different modes of transportation, whether separate or mixed, were all far below 0.5, most of them being close to zero.

could undergo urban decay. In other words, road pricing would have the perverse effect of decreasing the sustainability of the city in environmental terms, and probably in economic and social terms as well.

The aforementioned long-term trend towards unsustainability could be countered by imposing heavy restrictions on land use to prevent suburbanization. With only a few exceptions, such as Curitiba, municipal authorities in Latin America have not proven to be very adept at implementing such restrictions, however. At any rate, if they did so, they would run the risk of making the city a less attractive place to live, which would have an adverse effect on the prospects for economic development.

Imposing strict controls on parking would have different impacts, depending on the harshness of the measure. If the restriction were applied only to on-street parking, the restricted area could become more attractive for high-end residences, which would eventually slow the trend towards suburbanization, though it would certainly not halt it altogether.

## **H. LIGHTS AND SHADOWS OF DEMAND-SIDE ACTIONS**

It is clear that demand-side actions have a place in the battle against congestion and yield concrete results. To be sure, some are easier to implement than others, as they enjoy greater acceptance or less resistance among the citizenry. In addition, some are low in cost and others can be financed by the private sector, which increases their viability.

Regulating parking and staggering schedules seem to be the best choices according to the criteria indicated above. The optimum strategy could be a gradual implementation, combined with supply-side measures adopted in accordance with prevailing congestion levels. What does seem clear is that the struggle will be constant, unless the demand for transport decreases for other reasons.

Although they may require painstaking measures to implement and therefore be slow to yield results on a citywide scale, techniques aimed at changing driving habits and attitudes may also have a lasting impact that can really be felt during rush hour.

In any case, when demand-side measures are designed, side-effects must be weighed carefully and special attention must be given to preventing undesired effects, especially in the long term. In this regard, parking controls and road pricing are delicate matters, since poor design could result in depressed city districts or counterproductive consequences that undermine urban sustainability.



## Chapter V

### **SIMULATION AND EVALUATION OF ANTI-CONGESTION MEASURES IN THE CASE OF SANTIAGO, CHILE**

#### **A. TRANSPORT AND TRANSIT IN SANTIAGO**

Santiago, the capital of Chile, is not unfamiliar with the phenomenon of rising traffic congestion that plagues large cities, with the consequent increases in travel times, vehicle operating costs and environmental pollution. Projections for 2005 indicate that traffic speeds will worsen considerably, so the need to study and implement measures to help moderate and control congestion is inescapable.

The Interministerial Secretariat of Transport Planning (SECTRA) has developed the complex and proven computer models ESTRAS, VERDI and MODEM, which make it possible to analyse in advance the results that would be obtained from adopting certain decisions regarding the Santiago transportation system. These models were used to simulate the effects of various possible measures to control congestion and to evaluate their results in economic, social and environmental terms.

#### **1. A difficult situation that threatens to become unmanageable**

In 1991 a wide-ranging survey was conducted in Santiago of 32,000 households to determine what urban trips were made. The ESTRAS Model was calibrated on the basis of the results of that survey. The greatest density of motor vehicle trips occurs between 7:30 a.m. and 8:30 a.m., so that time period is considered the morning rush hour. The essential characteristics of transit and transport in Santiago during the morning rush hour are summed up in table V.1. This table also shows the projection for 2005, based on the assumption that the infrastructure and transport management will remain unchanged.

Table V.1  
**SANTIAGO: ESSENTIAL CHARACTERISTICS OF TRANSIT DURING  
MORNING RUSH HOUR (7:30 a.m. TO 8:30 a.m.)**

	1997	2005 <sup>a</sup>	Change 1997-2005
Number of trips	1 208 056	1 469 297	+ 22%
Total distance travelled (km)	10 411 568	13 209 551	+ 27%
Total time taken (hours)	702 021	1 254 441	+ 79%
Trips by bus (percentage)	52.4	47.1	-5.3%
Trips by car and taxi (percentage)	27.5	35.8	+ 8.3%
Trips by subway	4.2	4.7	+ 0.5%
Average bus trip			
Total distance <sup>b</sup> (km)	9.7	9.8	+ 1.0%
Total time <sup>b</sup> (minutes)	48	70	+ 46%
Speed of bus (km/h)	16	9	- 44%
Average car trip			
Distance (km)	9.5	9.8	+ 3.2%
Time (minutes)	22	39	+ 77%
Speed (km/h)	26	15	- 42%
Congested stretches	140	735	5.3 times

**Source:** G. Labarthe and D. Mery, "Informes ejecutivos de salidas del programa ESTR AUS", work prepared by Armonía Consultores for the Secretariat of Transport Planning and the Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile, unpublished, 1999 and 2000.

<sup>a</sup> Assumes no modification in transport capacity or management.

<sup>b</sup> Includes the distance travelled on foot and time spent waiting for the bus.

The following conclusions can be drawn about the morning rush hour from table V.1:

- The total number of trips made will increase at an average rate of 2.5% a year, or a cumulative 22% over the entire period.
- The total distance travelled by all vehicles will increase by 27%, while the total time taken will rise 79%.
- Although buses will account for the majority of trips, the modal distribution will change in favor of cars, and the subway will still account for less than 5%.
- Trip indicators suggest a major increase in congestion if corrective measures are not taken. Thus, an average trip by car for approximately the same distance will take 77% longer, whereas an average bus trip will take 46% longer.
- Although the rise in the number of trips and distances travelled appears moderate, all service indicators, especially speeds and travel times, will be significantly worse.
- Congestion levels in certain areas and streets of the city will become more severe and the sphere of influence will gradually expand, such that the number of congested stretches of roadway will quintuple. This is why a combination of measures aimed at controlling congestion must be considered.



## **2. The city has not remained idle**

Even before this diagnosis was carried out, the situation caused concern. Santiago has not sat idle in the face of progressive congestion, however; the situation could have grown much worse if various palliative measures had not been taken, including:

- Implementation of the SCAT centralized traffic signal control system, supported by a network of sensors that metre traffic in real time, contributing to improved programming of cycles and synchronization;
- Designation of bus-only lanes on the main artery;
- Construction of segregated lanes for buses on another major avenue;
- Expansion of the subway system;
- Substantial improvement of horizontal and vertical signposting;
- Redesign of numerous intersections, introducing left-turn lanes and other improvements;
- Widening and local rationalization of routes; and
- Prohibiting parking on several streets.

At any rate, the constant need to improve the flow of traffic prompted the study of new measures that were considered appropriate but whose impact had to be predicted to determine their benefits and effectiveness.

## **B. THE ESTR AUS AND VERDI MODELS**

### **1. The ESTR AUS Model**

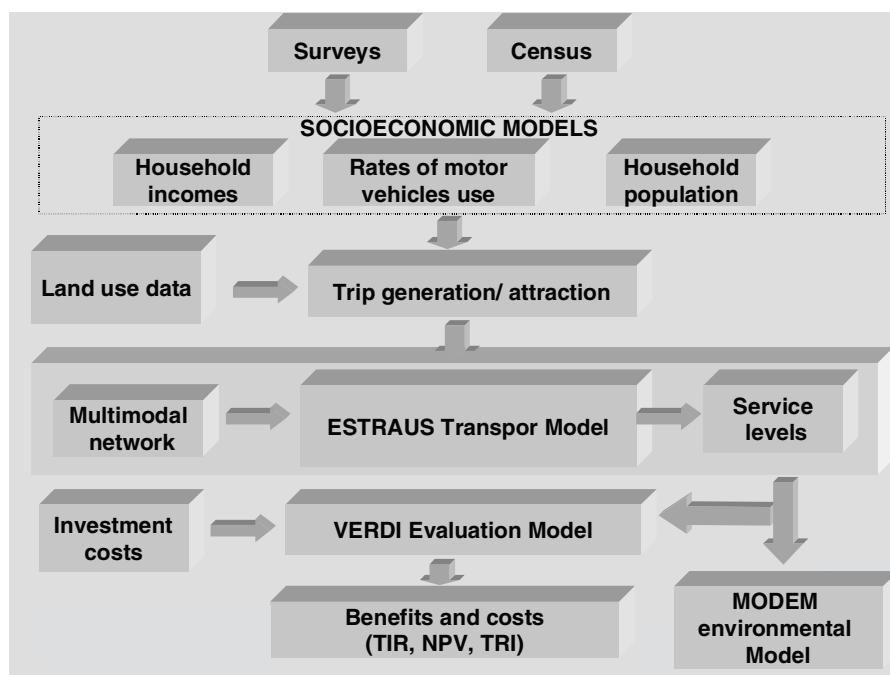
ESTRAUS (MIDEPLAN, 1997) is a model that balances transport supply and demand. It is applicable to multimodal urban transport networks with many different types of travellers (as a function of their income, the purpose of their trips, or other factors).

Travellers are classified according to the socioeconomic attributes of the household they belong to; for this purpose, average income and the number of vehicles owned are taken into consideration. The model assumes that in choosing among different available modes of transportation travellers apply a number of criteria, including costs, travel time and subjective preferences for one over another.

The multimodal network encompasses single modes of transportation, such as car, bus, taxi or subway, and combined modes, such as bus-subway, car-subway, etc. The model incorporates capacity restrictions for both private and public transportation, which allows it to treat congestion explicitly. It also incorporates the cost functions that exist on arcs (stretches of road) in the network.

The classic transport model features four stages: generation and attraction of trips, dispersal, modal distribution and allocation; the latter three are resolved simultaneously in ESTRAUS, while the first (generation and attraction of trips) is exogenous to the model. The structure of the model can be seen in figure V.1.

Figure V.1  
ESTRAUS, VERDI AND MODEM MODELS



Source: A. Thomas, "Planificación estratégica de sistemas de transporte urbano" (<http://www.cepal.org/Transporte/noticias/noticias/8/9178/Modelos.ppt>), March 2002.

Box V.1  
APPLICATION OF ESTRAUS IN SANTIAGO, CHILE

Features considered in the ESTRAUS Model for Santiago:

- 409 zones (areas into which the urban territory is divided);
- 2,374 nodes or intersections and 7,984 arcs or stretches of motorway joining the intersections;
- 13 categories of traveller, combining 5 different levels of income and 3 car ownership levels;
- 3 different trip purposes (work, school and other);
- 11 modes of transportation (7 single and 4 combined); and
- 741 bus lines with 507,000 associated route sections (virtual arcs of the bus network).

Source: G. Labarthe and D. Mery, "Informes ejecutivos de salidas del programa ESTRAUS", work prepared by Armonía Consultores for the Secretariat of Transport Planning and the Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile, unpublished, 1999 and 2000.

#### **(a) Results delivered by ESTRAUS**

The main results obtained from an ESTRAUS simulation are:

- Modal distribution (division of trips among the different modes of transportation) overall for the entire city modelled;
- Trip matrices (points of origin and destination for all travel) among the different zones of the entire system, subdivided by mode of transportation, purpose of trip and socioeconomic classification of the traveller;
- Levels of service (times and costs of travel) by mode of transportation, among zones in the network;
- Duration of trips on the network arcs;
- Flow of vehicles along the arcs (segments) of the road network;
- Flow of passengers along the arcs of the public transit networks;
- Sections of roadway that are congested; and
- Many other characteristics.

In other words, ESTRAUS delivers a complete representation of the urban transport system and all of its essential characteristics.

The analyses are carried out for two periods during the day: i) the morning rush hour, from 7:30 a.m. to 8:30 a.m., and ii) off hours, between 10:00 a.m. and 12:00 noon. The morning rush hour is when the urban transport system has the most unfavourable operating conditions, in terms of the number of trips by motor vehicle and the amount of congestion. The importance of dealing with this period correctly is fundamental, considering that transport systems are designed to meet the demand for travel that occurs at that time, in terms of motorway capacity and public transit fleets.

#### **(b) Analyses made possible by ESTRAUS**

The ESTRAUS Model makes it possible to predict the impact of two types of interventions on the urban transport system:

- Physical or infrastructure projects that are strategic in nature, generally applying to subway lines, urban divided highways, segregated systems for public surface transit and the like.
- Urban development or transport policies, such as road pricing, variations in the fuel tax, parking regulations, population relocation, changes in urban planning and others.

Measures involving the urban transport system can mean changes in the costs of travelling on different modes of transportation in different places. For example, charging for parking or raising the price can make car travel more costly, while introducing segregated lanes can reduce travel time for bus passengers. A major change in travel time or cost will result in a modification of the modal distribution.

When the impact of a given measure is calculated, the total number of trips in the period of analysis remains constant, and the model must determine the new spatial distribution of that invariable number of trips, how they are spread out among the different modes, what routes are chosen, new volumes of traffic, travel times and operating costs for each stretch of motorway, among other elements. To evaluate the impact of different measures, two scenarios are generated. One is the base or “no project” scenario, corresponding to the original situation; the other is the situation that would arise if the measure were applied, also known as the “with project” scenario. The results of a specific measure are portrayed as differences in relation to the base situation, which serves as a yardstick for comparison.

## **2. The VERDI Model**

VERDI is an evaluation model that analyses the economic impacts of a given intervention in the urban transport system (MIDEPLAN, 1999). VERDI uses the results derived from ESTRAUS for base and “with project” situations (figure V.1). The differences between the two make it possible to calculate the costs and benefits of the project associated with the simulation periods of the ESTRAUS Model.

Using expansion coefficients, it is possible to represent an entire day and year on the basis of the periods simulated with ESTRAUS. Repeating the exercise for successive years, the measures under study can be evaluated socially or privately. The principal indicator considered is the net present value (NPV).

VERDI includes two options for the social evaluation of projects, called:

- Classic evaluation, or resource savings evaluation, and
- Evaluation of benefits to travellers

### **(a) Classic or resource savings evaluation**

In the classic evaluation approach, the project’s benefits and costs are the positive or negative variations in resource consumption, which in the case of transportation essentially means travel times and vehicle operating costs. If in the “with project” scenario the total of all these costs is less than in the base situation, the measure has benefits equal to the difference, and vice-versa. The benefits must be compared with the costs of implementing the measure.

### **(b) Evaluation of benefits to travellers**

The option of evaluating the benefits to travellers estimates the total benefits of the project as the variation in the surpluses enjoyed by consumers (those who use the transport system) and those accruing to the producers of transport services (operators). In the case of transport, a surplus is the difference between the costs a person is willing to incur and those he must actually pay

to travel.<sup>1</sup> The surplus is a sort of margin or gain received by the user. In other words, this system of evaluation considers subjective aspects, including the well-being or gain that travellers derive from using each mode of transportation. This reflects the different preference for each mode, as people are willing to pay more for those considered most attractive; the car generally heads the list of preferences because of its greater versatility for travelling.

Thus, if a particular measure raises the cost of travelling on a mode, users of that mode suffer a loss, as their margin of gain diminishes; some must even switch to a lower-cost alternative that is less valued by them, which also diminishes their margin. This would be the case, for example, of motorists who might switch to the bus in the face of road pricing or a change in the cost of parking that made driving by car cost more than they are willing to pay. This would apply to bus passengers if the measure in question increased their travel speed.

In contrast to this traveller benefit scheme, classic evaluation is limited to measuring the impacts on the economy in terms of the variation in travel costs.

### **(c) Classic and traveller benefit evaluations sometimes disagree**

The two evaluations do not always yield the same results (both favourable or both unfavourable), contrary to what one might assume at first glance. Sometimes a negative result is obtained when all the variations in surpluses or traveller benefits are summed up for the entire transport system of a city; this means that the majority of travellers suffer a loss of well-being or satisfaction. At the same time, however, the classic evaluation can yield positive results if there is a decline in total transport costs, that is, if fewer resources are used to move all the travellers.

## **C. SUMMARY OF SIMULATIONS AND EVALUATIONS**

Santiago has adopted anti-congestion measures, but it is necessary to pursue new measures to improve the supply and operation of infrastructure and public transportation, and to act on demand as well, that is, on the use of vehicles. Otherwise, the pressure exerted by demand can exceed any available infrastructure.

The ESTRAS and VERDI Models were used to analyse a diverse set of options for dealing with congestion while also improving the economic efficiency of urban transport and helping to curb environmental pollution. When the measures were proposed, special attention was given to the less affluent social classes which are frequently captive users of public transit.

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<sup>1</sup> Technically, the surplus corresponds to the area below the demand or supply curve and above transport costs.

The measures considered, which basically involve stimuli for public transit and disincentives for car use, are the following:

- Segregated bus lanes
- Executive buses
- Various levels of parking prohibition
- Road pricing, with different degrees of coverage and toll rates
- Segregated bus lanes along with prohibiting on-street parking
- Segregated bus lanes along with road pricing

The proposed measures are described below, with a summary of their characteristics and the principal impacts that would result in each case, using data from 1997. In each case, the decision on whether to implement the measure will also have to take into account acceptance by the citizenry, as resistance by the citizens would render it unviable.

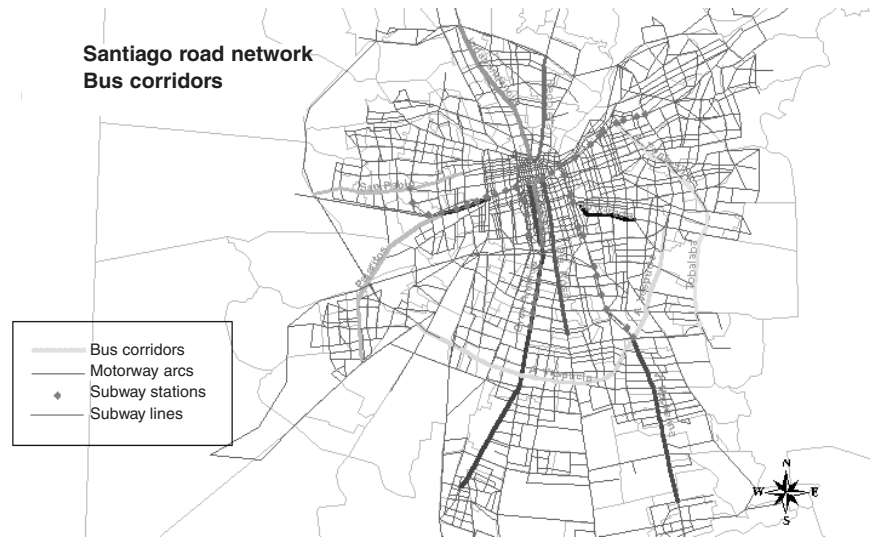
## **1. Segregated bus lanes**

### **(a) Description**

Segregated lanes are stretches of pavement isolated from the rest of the motorway by a physical barrier, and they are reserved solely for bus traffic. This allows buses to travel more smoothly and avoid friction with other vehicles on the roadway.

The impact of segregated lanes was analysed previously (Fernández and De Cea, 1999). Implementation was considered for the principal arteries of Santiago, such as Pajaritos, Santa Rosa, Vicuña Mackenna, Independencia, Alameda, Gran Avenida, Tobalaba, Américo Vespucio, San Pablo and Recoleta (see map V.1). There would be one 3.5-metre lane in each direction, except in places where bus stops are located, where there would be two lanes to make it easier to go around stopped buses; the distance between stops ranges from 500 to 600 metres. The results listed below come from the aforementioned study.

Map V.1  
**SEGREGATED BUS LANES**



**Source:** Fernández y De Cea, Ingenieros Ltda., “Análisis estratégico de los impactos sobre la demanda de implementar un plan de corredores para el gran Santiago”, study for the Ministry of Planning and Cooperation (MIDEPLAN), Santiago, Chile, 1999.

### **(b) Principal results obtained with ESTRAUS**

There is a change in the modal distribution favoring buses, with a nearly 0.4% increase in demand for buses among all trips. The shift occurs mainly from subway and bus-subway travel.

Significant decreases in travel time are produced. Travel on public transit takes approximately five minutes less on average. Car drivers also realize savings of 1.5 minutes per trip. Total time saved amounts to about 40 million hours per year. These results have been more than corroborated by experiments with segregated lanes and bus-only streets introduced in Santiago (see chapter III section E).

The shorter travel time means higher speeds for both buses and cars. It can be deduced that physical separation of types of traffic benefits public transport, and in particular leads to a general easing of congestion.

Consequently, this measure is deemed highly effective, and it has the virtue of favouring cars at the same time.

### (c) Principal results obtained with VERDI

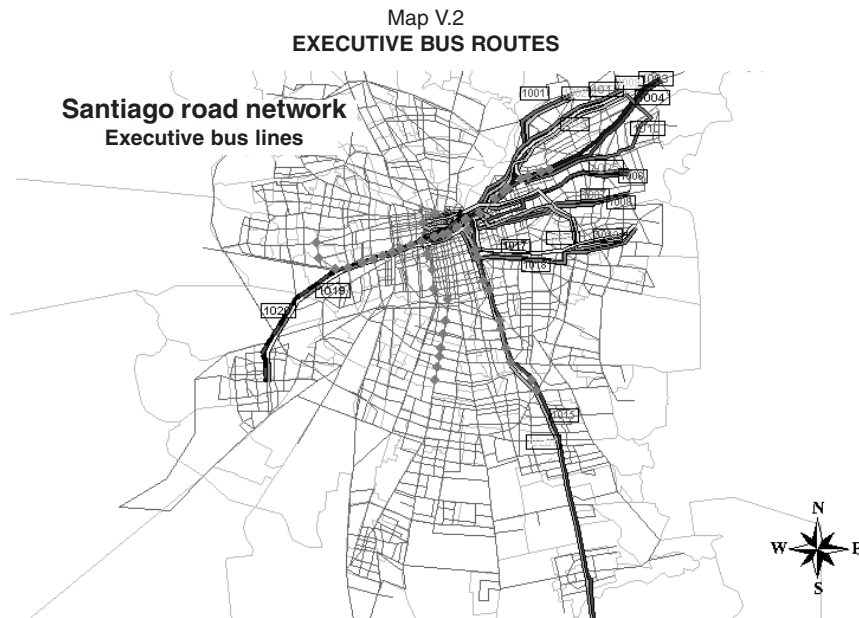
The principal results of the study (Fernández and De Cea, 1999) are that in the first year of implementation there is an annual resource savings of US \$57.3 million. Moreover, because of the greater travel speeds, 700 fewer buses are required to deliver the same service, with an existing fleet of approximately 10,000 buses. Obviously, carrying out the segregation will require an investment (about US \$637 million), but the long-term savings make the measure socially advantageous.

## 2. Executive buses

### (a) Description

Executive buses are high-quality multi-passenger vehicles. In the study for Santiago (CIS, 1995), they were assumed to have reclining seats, piped music, air conditioning, uniformed drivers, well-spaced stops and smart cards or subscription fares.

The establishment of 10 routes was considered (see map V.2), with two variants: i) 24-passenger buses circulating every 20 minutes, and ii) 40-passenger buses circulating every 12 minutes. A fare of 1,200 pesos was assumed, equivalent to US \$2.61, which is between five and six times the regular bus fare.



**Source:** Asociados Consultores en Transporte Ltda. (CIS), "Investigación de la factibilidad de implementación de un sistema de servicios especiales de locomoción colectiva para la ciudad de Santiago", study carried out for the Ministry of Transport and Telecommunications, Santiago, Chile, 1995.



## (b) Principal results obtained from ESTR AUS

The principal results are shown in table V.2. It should be noted that for technical reasons related to the way the level of preference for executive buses was modelled, the results of the application of the ESTR AUS Model are not as precise as in the other cases studied, so they should be regarded as preliminary.

It can be seen that this system can attract nearly 2.4% of all trips made during morning rush hour, which is rather significant in view of the fact that this amounts to more than half the number of trips made by subway. Time spent waiting for executive buses is 68% less in the design with the higher capacity and frequency.

During rush hour, 33% of trips on executive buses, or about 6,700, would be made by people with high and medium-high incomes who, if this option were not available, would travel alone or carpool in private cars. In addition, 40% of the passengers would come from regular buses. Subway riders from the upper economic strata would also be attracted.

**Table V.2**  
**SANTIAGO: EXECUTIVE BUSES, RESULTS OF ESTR AUS**  
**(FOR RUSH HOUR) AND VERDI MODELS**

	Base	ExecBus1	ExecBus2
Total distance travelled (km)	10 411 568	+8 497	+21 938
Total time taken (hours)	701 021	+5 874	+10 685
Bus trips (percentage)	52.4	-0.91	-0.93
Car and taxi trips (percentage)	27.5	-0.5	-0.82
Subway trips (percentage)	4.2	-0.13	-0.18
Executive bus trips	—	+1.87	+2.36
Average bus trip			
Total distance including walking (km)	9.7	+0.06	-0.13
Total bus trip time (minutes)	48	-0.36	-0.82
Bus speed (km/h)	16	+0.22	+0.02
Average car trip			
Distance (km)	95	-0.02	+0.31
Time (minutes)	22	-0.38	+0.87
Speed (km/h)	26	+0.43	-0.18
Congested stretches (number)	140	-5	+8

**Source:** G. Labarthe and D. Mery, "Informes ejecutivos de salidas del programa ESTR AUS", work prepared by Armonía Consultores for the Secretariat of Transport Planning and the Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile, unpublished, 1999 and 2000.

ExecBus1: Capacity 24 passengers, frequency 3 times an hour.

ExecBus2: Capacity 40 passengers, frequency 5 times an hour.

The average characteristics of bus and car trips improve slightly when smaller executive buses are introduced. The same is true of bus trips when larger executive buses are employed, whereas car trips deteriorate slightly in this scenario. What happens is that executive buses do not replace a sufficient number of car trips, and with larger executive buses, the number of congested stretches of roadway actually increases.

It is concluded that in the case of Santiago, introducing medium-sized executive buses (24 passengers) makes a contribution, albeit a modest one, to combating congestion; in contrast, introducing large buses is ineffective and even counterproductive.

### **(c) Principal results obtained with VERDI**

They were not determined in this study.

Nevertheless, the operation of medium-sized executive buses is advantageous from a private point of view (CIS, 1995) during rush hour. In other words, revenues from fares would offset the costs of the vehicles and their operation.

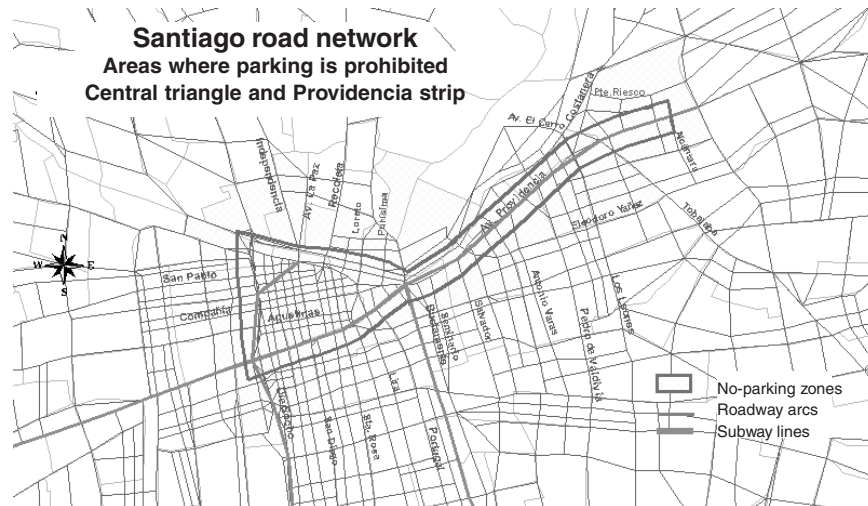
## **3. Prohibiting parking**

### **(a) Description**

Prohibiting parking in certain areas means increasing the cost of travelling by car to those areas. The following four levels of parking prohibition were considered in downtown Santiago plus Avenida Providencia during morning rush hour (see map V.3):

- Prohibiting on-street parking in places without parking metres;
- The above plus prohibiting off-street parking in paid areas; and
- The above plus prohibiting off-street parking in free areas.

Map V.3  
AREAS WHERE PARKING IS PROHIBITED



**Source:** G. Labarthe and D. Mery, “Informes ejecutivos de salidas del programa ESTRAUS”, work prepared by Armonía Consultores for the Secretariat of Transport Planning and the Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile, unpublished, 1999 and 2000.

Parking prohibition was simulated, with an extremely high price assigned for parking in prohibited places. The principal results are shown in table V.3. It should be pointed out that parking restrictions in private places are difficult to implement, and legislation may have to be amended to make them possible.

Table V.3  
**SANTIAGO: PROHIBITING PARKING, RESULTS OF ESTR AUS  
(FOR RUSH HOUR) AND VERDI MODELS**

	Base	W/OM	WM	PD	FR
Total distance travelled (km)	10 411 568	+1 638	+18 643	+21 292	+21 980
Total time taken (hours)	701 021	-2 561	-2 382	-12 537	-24 338
Bus trips (percentage)	52.4	+0.03	+0.04	+0.28	+0.49
Car and taxi trips (percentage)	27.5	-0.08	-0.09	-0.36	-0.63
Subway trips (percentage)	4.2	-0.03	-0.03	+0.01	+0.05
Average bus trip					
Total distance including walking (km)	9.7	0	+0.02	+0.03	+0.06
Total bus trip time (minutes)	48	-0.15	-0.20	-0.91	-1.65
Bus speed (km/h)	16	+0.08	+0.16	+0.54	+1.04
Average car trip					
Distance (km)	9.5	0	+0.01	-0.02	-0.09
Time (minutes)	22	-0.25	-0.17	-0.86	-1.75
Speed (km/h)	26	+0.31	+0.23	+1.03	+2.03
Congested stretches (number)	140	-2	-8	-28	-42
Resource savings (millions of dollars/year)		+3.4	+3.4	+16.4	+31.7
Benefits to travellers (millions of dollars/year)		+8.1	+19.4	+15.8	+33.0

**Source:** G. Labarthe and D. Mery, "Informes ejecutivos de salidas del programa ESTR AUS", work prepared by Armonia Consultores for the Secretariat of Transport Planning and the Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile, unpublished, 1999 and 2000.

W/O M: prohibiting on-street parking in places without parking metres.

WM: W/O M plus prohibiting on-street parking in places with parking metres.

PD: WM plus prohibiting off-street parking in paid areas.

FR: PD plus prohibiting off-street parking in free areas.

## (b) Principal results obtained with ESTR AUS

When the different measures are analysed, a very slight improvement can be seen in operating variables in the scenarios that seem most feasible and that correspond to prohibiting parking on the street. This may be due to the fact that Santiago already had a reasonable restriction in this regard.

The situation changes for the better when the prohibition is expanded to off-street parking during rush hour. In the case of the greatest prohibition, the share of cars in total travel drops by 0.6%. About 12,100 trips (0.1%) are subtracted from the single-occupant car mode; 40% of these drivers would switch to a car with more than one occupant, while the rest would switch to public transit. With fewer cars competing for land use, travel times fall by about two minutes and speed rises by two km/h.

Travel times for public transport also decrease, with the consequent increase in speed. The savings are similar for buses and cars.

The number of congested stretches of motorway declines to as little as 42, which is similar to the level seen in certain road pricing scenarios.

It can be concluded that if a city has already taken control over on-street parking, as Santiago has done, measures of this type for the purpose of reducing congestion would have to be harsh enough to discourage people from commuting to work by car, which is represented by the scenarios of maximum prohibition.

### (c) Principal results obtained with VERDI

In keeping with the results of ESTRAUS, resource savings are low when on-street parking is banned, and the most restrictive scenarios appear the most attractive. As parking becomes more restricted, the benefits to travellers increase commensurately.

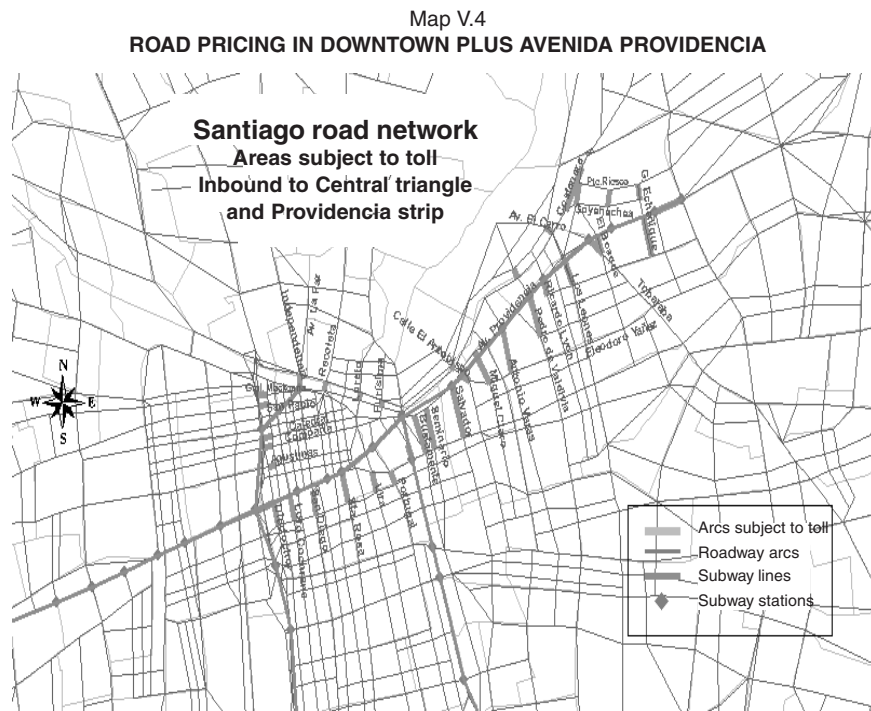
The travellers who benefit the most are those in the lower-middle income group who do not have cars, and students in the middle-income strata. Those who suffer the most losses are upper-middle income travellers who own two or more cars.

## 4. Road pricing

### (a) Description

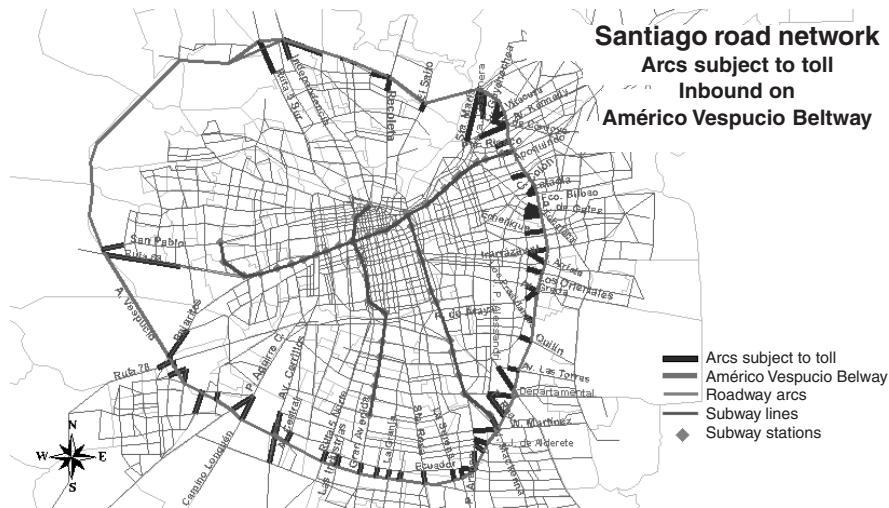
Road pricing consists of charging a fee during periods of peak traffic for travelling on specific streets or in specific areas where congestion is prevalent.

In the Santiago study, three concentric areas were identified for the application of this measure (see maps V.4 and V.5), and different tolls were indicated for each one (see table V.4).



**Source:** G. Labarthe and D. Mery, "Informes ejecutivos de salidas del programa ESTRAUS", work prepared by Armonía Consultores for the Secretariat of Transport Planning and the Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile, unpublished, 1999 and 2000.

Map V.5  
AMÉRICO VESPUCCIO BELTWAY



**Source:** G. Labarthe and D. Mery, "Informes ejecutivos de salidas del programa ESTR AUS", work prepared by Armonía Consultores for the Secretariat of Transport Planning and the Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile, unpublished, 1999 and 2000.

Table V.4  
SANTIAGO: ROAD PRICING SCENARIOS

Pricing area	Toll (1997 prices)	Code
Downtown plus	Entrance to area: 500 pesos	C500
Avenida Providencia	Entrance to area: 1 000 pesos	C1000
	Entrance to area: 2 000 pesos	C2000
Area inside	Entrance to area: 1 000 pesos	AV1000
A. Vespucio Beltway	Entrance to area: 2 000 pesos	AV2000
	Entrance to area and toll for internal circulation: 1 000 pesos	AVI1000
All of Santiago	Internal circulation: 1 000 pesos	GS1000
	Internal circulation: 2 000 pesos	GS2000

**Source:** Internal compilation.

The city centre and the area surrounding Avenida Providencia are where most travellers are headed. Avenida A. Vespucio is a beltway that encompasses most of the populated area of the city. The tolls, equivalent to US \$1.09, US\$ 2.17, and US \$4.35, respectively, were selected according to what was considered acceptable. Tolls of less than 500 pesos would be too small to induce motorists to make significant behavioural changes.

The principal results are shown in tables V.5 and V.6.

Table V.5  
**SANTIAGO: ROAD PRICING MEASURES, RESULTS OF ESTRASUS  
(FOR RUSH HOUR) AND VERDI MODELS**

	Base	C500	C1000	C2000	AV1000
Total distance travelled (km)	10 411 568	+93 951	+106 253	+145 188	+19 349
Total time taken (hours)	701 021	-11 868	-9 322	-3 020	-19 378
Bus trips (percentage)	52.4	+0.56	+0.63	+0.76	+1.06
Car and taxi trips (percentage)	27.5	-0.42	-0.73	-0.83	-1.22
Subway trips (percentage)	4.2	+0.02	+0.03	+0.07	+0.02
Average bus trip					
Total distance including walking (km)	9.7	+0.07	+0.07	+0.07	+0.15
Total bus trip time (minutes)	48	-1.57	-1.63	-1.65	-1.38
Bus speed (km/h)	16	+0.85	+0.91	+0.95	+1.06
Average car trip					
Distance (km)	9.5	+0.15	+0.19	+0.31	-0.26
Time (minutes)	22	+0.46	+0.96	+2.01	-1.89
Speed (km/h)	26	-0.11	-0.6	-1.43	+1.74
Congested stretches (number)	140	-23	-15	-1	-36
Resource savings (millions of dollars/year)		+5.8	+3.3	-3.4	+40.5
Benefits to travellers (millions of dollars/year)		-87.7	-107.5	-125.2	-289.1
Cars paying toll (per day)		10 924	6 284	1 434	39 082
Revenues (millions of dollars/day)		11.9	13.7	6.2	85.0

**Source:** G. Labarthe and D. Mery, "Informes ejecutivos de salidas del programa ESTRASUS", work prepared by Armonía Consultores for the Secretariat of Transport Planning and the Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile, unpublished, 1999 and 2000.

C500, C1000, C2000 = inbound to city centre + Avenida Providencia with toll of 500, 1,000 and 2,000 pesos, respectively.

AV1000 = inbound to A. Vespucio Beltway with toll of 1,000 pesos.

Table V.6  
**SANTIAGO: ROAD PRICING MEASURES, RESULTS OF ESTRAUS  
(FOR RUSH HOUR) AND VERDI MODELS**

	Base	AV2000	AVI1000	GS1000	GS2000
Total distance travelled (km)	10 411 568	+8 541	+136 284	+88 425	+137 687
Total time taken (hours)	701 021	-29 212	-27 438	-24 289	-35 241
Bus trips (porcentaje)	52.4	+1.81	+1.86	+1.26	+1.96
Car and taxi trips (percentage)	27.5	-2.02	-2.22	-1.42	-2.22
Subway trips (percentage)	4.2	+0.04	+0.12	+0.02	+0.02
Average bus trip					
Total distance including walking (km)	9.7	+0.21	+0.17	-0.06	-0.08
Total bus trip time (minutes)	48	-2.18	-2.77	-2.65	-3.81
Bus speed (km/h)	16	+1.68	+1.95	+1.18	+1.85
Average car trip					
Distance (km)	9.5	-0.48	+0.11	+0.44	+0.67
Time (minutes)	22	-2.97	-1.23	-0.14	-0.39
Speed (km/h)	26	+2.65	+1.93	+1.42	+2.38
Congested stretches (number)	140	-52	-48	-30	-55
Resource savings (millions of dollars/year)		+40.5	+38.0	+24.8	+40.6
Benefits to travellers (millions of dollars/year)		-366.0	-258.3	-31.3	-43.5
Cars paying toll (per day)		28 307	39 858	155 283	168 970
Revenues (millions of dollars/day)		123.1	86.7	337.6	367.3

**Source:** G. Labarthe and D. Mery, "Informes ejecutivos de salidas del programa ESTRAUS", work prepared by Armonia Consultores for the Secretariat of Transport Planning and the Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile, unpublished, 1999 and 2000.

AV2000 = Inbound to A. Vespucio Beltway with toll of 2,000 pesos.

AVI1000 = Inbound to A. Vespucio Beltway and internal circulation with toll of 1,000 pesos.

GS1000 = Internal circulation throughout Santiago with toll of 1,000 pesos.

GS2000 = Internal circulation throughout Santiago with toll of 2,000 pesos.

Road pricing has been debated in the National Congress of Chile since 1991, with various formulas under consideration. Although the Chamber of Deputies passed legislation, the matter has been tabled in the Senate, and passage seems a remote possibility. The reasons for the resistance are analysed in chapter IV.

### **(b) Principal results obtained with ESTRAUS**

It should be mentioned, first of all, that road pricing in the area of Downtown plus Providencia yields inauspicious results. The speed of buses and their attraction of passengers increases, but car circulation worsens. The total savings in resources is modest. The most noteworthy aspect is that as tolls rise, the already limited effectiveness of the measure declines until it even becomes negative. This is because the area subject to pricing, though the destination of a large number of trips, comprises a small proportion of the total area of the city. As a result, those not going downtown have an incentive to circumvent that area to get to their destinations, which lengthens the distance and time of many trips and cancels out many of the advantages yielded by buses. Furthermore, with a higher toll, congestion is shifted to other streets. Therefore, implementing road pricing in the city centre alone does not appear advisable.



The results are better in the other scenarios, with an increasing tendency to expand the area and raise tolls.

Buses could enhance their share of trips by 1% to 2%, while the opposite would occur, though in greater proportions, for car and taxi trips.

An interesting increase in average speeds for both private and public transportation is seen, in some cases by more than two km/h. Travel times fall in all cases, especially for buses. This is reflected in less total time spent travelling during rush hour, although in some scenarios there are sharp increases in the total distance travelled.

The effect on the number of congested stretches of roadway is variable. The best results, logically, occur in the scenario with the highest toll (all of Santiago at 2,000 pesos), in which 55 stretches cease to be congested.

### **(c) Principal results obtained with VERDI**

In general, the benefits calculated in terms of resource savings rise along with the amount of the toll charged, to as high as US \$41 million per year in the most restrictive case.

Benefits calculated under the traveller benefits methodology, in contrast, are negative in every case, and the results grow even worse as the toll rises. This is because when the toll is implemented, the difference between what drivers are willing to pay and the actual cost they must pay diminishes; in fact, a certain number switch to a less preferred mode, such as the bus, if the cost of driving their cars exceeds what they find acceptable.

The analysis by socioeconomic level indicates that all strata not owning cars are benefited because of the enhanced flow of bus traffic. The opposite happens to car owners. The group losing the most is the upper-middle income segment who own two or more cars.

All of the scenarios involve collecting revenues from tolls, which in the maximum case amount to more than US \$90 million gross, assuming 250 business days per year.

## **5. Combining segregated bus lanes with parking prohibitions**

### **(a) Description**

The aforementioned segregated bus lanes are combined with parking prohibitions during rush hour in the Providencia strip and downtown, on the street in areas with and without parking metres.

The main results are seen in table V.7.

Table V.7  
**SANTIAGO: SEGREGATED BUS LANES COMBINED WITH PARKING  
PROHIBITIONS ON THE STREET (WITH AND WITHOUT PARKING  
METRES). RESULTS OF THE ESTRAUS (FOR RUSH HOUR)  
AND VERDI MODELS**

	Base	SE+Pkg
Total distance travelled (km)	10 411 568	+36 163
Total time taken (hours)	701 021	-52 668
Bus trips (percentage)	52.4	+0.48
Car and taxi trips (percentage)	27.5	-0.23
Subway trips (percentage)	4.2	-0.09
Average bus trip		
Total distance including walking (km)	9.7	+0.07
Total bus trip time (minutes)	48	-4.37
Bus speed (km/h)	16	+2.73
Average car trip		
Distance (km)	9.5	-0.05
Time (minutes)	22	-1.17
Speed (km/h)	26	+1.34
Congested stretches (number)	140	-19
Resource savings (millions of dollars/year)		13.2
Benefits to travellers (millions of dollars/year)		92.8

**Source:** G. Labarthe and D. Mery, "Informes ejecutivos de salidas del programa ESTRAUS", work prepared by Armonía Consultores for the Secretariat of Transport Planning and the Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile, unpublished, 1999 and 2000.

SE + Pkg = Segregated lanes plus parking prohibitions.

### **(b) Principal results obtained with ESTRAUS**

Although an exhaustive comparison cannot be made because the evaluations were done separately, the results are not very different from those obtained from segregated bus lanes. That was to be expected, since there is little to gain from prohibiting on-street parking in an area where there are few parking places anyway.

The changes in modal distribution are minimal, though in the case of buses they are greater, with an additional 0.5% of travellers attracted.

Car and bus travel times diminish, with the improvements for the latter being much greater at more than four minutes. This makes major inroads into the time spent travelling during rush hour. Distances travelled do not change substantially.

The measure reduces by 19 the number of congested stretches of motorway.

### (c) Principal results obtained with VERDI

The savings in resources amount to more than US \$13 million a year, a modest sum.

Unlike road pricing, this scenario yields positive results when evaluated according to traveller benefits. The resulting figure is nearly US \$93 million, primarily due to the significant time savings by bus passengers, on the order of 42,000 hours for each peak hour. All socioeconomic strata improve their situation under this measure.

The fleet of buses could be reduced by about 570 units with the same level of service.

## 6. Combining segregated bus lanes with road pricing

### (a) Description

Segregated bus lanes are combined with a toll of 2,000 pesos for entering the area defined by the A. Vespucio Beltway.

The principal results are seen in table V.8.

Table V.8

#### SANTIAGO: SEGREGATED BUS LANES COMBINED WITH A TOLL OF 1,000 PESOS FOR CROSSING THE AMÉRICO VESPUCIO BELTWAY. RESULTS OF THE ESTRAS (FOR RUSH HOUR) AND VERDI MODELS

	Base	SE+AV2000
Total distance travelled (km)	10 411 568	+31 160
Total time taken (hours)	701 021	-69 952
Bus trips (percentage)	52.4	+2.16
Car and taxi trips (percentage)	27.5	-2.15
Subway trips (percentage)	4.2	-0.04
Average bus trip		
Total distance including walking (km)	9.7	+0.30
Total bus trip time (minutes)	48	-5.54
Bus speed (km/h)	16	+4.09
Average car trip		
Distance (km)	9.7	-0.61
Time (minutes)	22	-3.60
Speed (km/h)	26	+3.25
Congested stretches (number)	140	-70
Resource savings (millions of dollars/year)		+45.8
Benefits to travellers (millions of dollars/year)		-284.7
<b>Pagan tarifa (autos/día)</b>		27 877
<b>Recaudación (millones dólares/día)</b>		121.23

**Source:** G. Labarthe and D. Mery, "Informes ejecutivos de salidas del programa ESTRAS", work prepared by Armonía Consultores for the Secretariat of Transport Planning and the Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile, unpublished, 1999 and 2000.

SE + AV2000 = Segregated lanes combined with a toll of 2,000 pesos for crossing A. Vespucio.

### **(b) Principal results obtained with ESTRAUS**

This combination of measures is seen to be very effective with respect to modal distribution, as the number of those driving private cars falls by more than 2% and the number taking the bus rises by the same amount.

Major time savings (3.6 minutes) and increases in speed (3.3 km/h) for cars are realized. The gains for public transit are much more pronounced, with trip times falling by more than five minutes and speeds rising by more than four km/h.

Nearly 70,000 hours are saved during rush hour, which translates into a decrease of 10% in total travel time. Most is saved by bus riders (more than 40,000 hours).

In turn, congested stretches are cut by 70, that is, by half.

### **(c) Principal results obtained with VERDI**

As with the road pricing scenarios, contrasting results are seen between the traveller benefit and resource savings evaluations.

Benefits calculated in terms of resource savings are positive, totalling nearly US \$46 million per year. On the other hand, the evaluation of benefits to travellers shows losses of nearly US \$285 million per year. The greatest decline in benefits is experienced by high-income travellers who own two or more cars, while the lowest-income strata who do not own cars receive positive results.

Higher bus speeds allow for a fleet reduction of 900 units, approximately 9%.

Charging a toll would yield more than US \$30 million in gross revenues per year.

## **D. RECOMMENDATIONS FOR SANTIAGO**

### **1. Progress achieved by previous measures**

Santiago is a city that has not started from scratch when it comes to controlling congestion. Consequently, the results achieved by the modelling should be analysed based on existing conditions, which are mentioned in section A.2 of this chapter. Centralized traffic light control, bus-only lanes and segregated bus lanes on two streets, expanding the subway system, substantial improvements in horizontal and vertical signposting, redesigning numerous intersections, local rationalization of routes, and a certain level of on-street parking prohibition had all made major contributions.

It is difficult to quantify the contribution of the measures adopted previously, but it is clear that they have kept traffic speeds from declining

significantly. Centralized traffic light control may have played a great role, as evidenced by the traffic chaos and heavy congestion in many parts of the city that occurred one day when a criminal act took the computers off line and the traffic lights reverted to basic individual programming or were deactivated.

## **2. Recapitulation of the measures' results**

From the standpoint of saving resources, the most plausible results are derived from segregated bus lanes and some road pricing scenarios. When traveller benefits are considered, segregated bus lanes clearly stand out, while all road pricing schemes yield negative results.

Prohibiting off-street parking, whether paid or free, during rush hour in the city centre also appears to be an interesting prospect. Nonetheless, it may be advisable to leave this measure for later, when the battle against congestion needs a new impetus, perhaps by offering incentives not to commute to work by car, as long as there is a good public transportation system. At any rate, care would have to be taken to prevent this measure from driving businesses out of the city centre.

Prohibiting on-street parking more than is currently done, introducing executive buses, and road pricing downtown have insignificant and, in two cases, even counterproductive results.

In terms of self-sustainability or financing, road pricing measures would generate sufficient revenues to offset the costs involved in control systems, and might even yield surpluses. One possible exception is road pricing in the downtown area alone, which would not produce major revenues. In contrast, segregated lanes require someone to underwrite the cost of establishing them, which may be high if expropriation is required, and also maintaining them. An executive bus system would apparently pay for itself.

From the above considerations, it can be deduced that the most appropriate measure, the one that would lead to a major reduction of congestion in Santiago as it stands today, appears to be the introduction of segregated bus lanes. Little value would be added by imposing additional on-street parking prohibitions; the latter aspect could be handled by making an ongoing assessment of thoroughfares that should continue providing on-street parking.

Although implementing road pricing alone or combined with segregated lanes could reduce the number of congested stretches of motorway, it cannot be ignored that all evaluations are negative when traveller benefits are taken into account. In addition, there is strong resistance to tolls, and it is unlikely that legislation making it feasible will pass.

Besides establishing segregated lanes, introducing medium-sized executive buses might be a complementary measure, provided that it is self-sustaining.

### **3. Can the recommendations be extrapolated?**

Any set of conclusions should be considered in the context in which they were reached, so it would be risky to give advice to other cities based on the studies carried out in Santiago. In particular, this metropolis has made progress in managing congestion, and it is under those circumstances that segregated bus lanes appear to be the most advisable alternative.

Nonetheless, Santiago's experience highlights some measures that are worthy of consideration in other cities, though always with the proper studies and adaptations to local conditions.

Apparently, the most positive effects could be gained from a centralized traffic light control system coupled with segregated lanes for public transit, which could even lead to the reorganization of routes into trunk and feeder lines. The rationalization of on-street parking, improved signposting and improvements in the design of intersections and the width of streets should not be ruled out and in fact should be an ongoing effort.

## Chapter VI

### CONGESTION AND ENVIRONMENTAL POLLUTION

Vehicular congestion and atmospheric pollution are two major problems that plague modern cities, especially in developing countries. The two have causes in common. Congestion is produced by the operation of motor vehicles on streets and avenues of limited capacity. Pollution is produced because contaminant emissions, of which vehicles account for a large percentage, exceed the absorption and dilution capacity of the basin in which the city is located. Therefore, it is reasonable to expect that transport policies and measures designed to reduce congestion in a city will also have an effect on air pollution.

This chapter describes the influence of vehicular congestion control measures on emissions of atmospheric contaminants. In addition, based on measures to ease congestion that were studied for the city of Santiago, Chile, the impact of pollutants on the population's health is modelled, and finally, the social benefits of reducing benefits are compared with those derived from cutting atmospheric contaminants.

#### A. ATMOSPHERIC CONTAMINANTS

Atmospheric contaminants can be classified into two large groups: i) those that have local and regional effects and ii) those that have global or planetary effects.

##### 1. Atmospheric contaminants with local and regional effects

The main atmospheric contaminants are particulate matter, sulphur dioxide, carbon monoxide, ozone, nitrogenous oxides and volatile organic compounds. In addition, many heavy metals are present in particulate matter in the atmosphere.

The term "primary contaminants" refers to those introduced directly into the atmosphere by the phenomena that produce them; "secondary contaminants" are those that form in the atmosphere because of the presence of primary contaminants.

The particulate matter (PM) in the atmosphere is a complex mixture of organic and inorganic substances, ranging from sea salt and soil particles to soot particles produced by burning fossil fuels. Particulate matter from combustion can be emitted directly, in the form of elemental and organic carbon, or it can form in the atmosphere from other contaminants. It can also be emitted when street dust is resuspended. The total particulate matter present in the atmosphere is called total particles in suspension (TPS). Finer particles are labelled according to their size; for example, PM10 encompasses all particles with a diameter of less than 10 microns,<sup>1</sup> and PM<sub>2.5</sub> includes all those smaller than 2.5 microns.

Sulphur dioxide or sulphurous anhydride (SO<sub>2</sub>) is a colourless gas that occurs because of the presence of sulphur in fuel, primarily diesel. It later oxidates in the atmosphere and produces sulphates, which are part of the particulate matter. SO<sub>2</sub> in the presence of particulate matter forms a lethal mixture; this mixture has been responsible for episodes such as that of 1952 in London, when thousands of people died.

Carbon monoxide (CO) is an odourless, colourless gas that comes about because of incomplete combustion. CO prevents the blood from transporting oxygen, and in high concentrations it causes death.

Ozone, an oxidant, is the main atmospheric contaminant constituting what is known as photochemical smog, which is produced by chemical reactions in the atmosphere in the presence of ultraviolet radiation. The aerosols that form as part of the photochemical process result in reduced visibility, giving the atmosphere a reddish brown appearance.

The most important nitrogenous oxides are nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>). NO<sub>2</sub> absorbs light in the visible range, which lessens visibility. NO<sub>2</sub> is part of the chain reaction that leads to the formation of photochemical smog.

And finally, many heavy metals can be found in the atmosphere. Lead is perhaps the most common of them because of its use as an additive in regular gasolines.

## **2. Impacts of atmospheric contaminants with local and regional effects**

Atmospheric contaminants can have various effects. The main ones are an impact on public health, harm to vegetation and ecosystems, damage to materials and reduced visibility. Because of its greater importance, human health is the focus of this analysis, although the other effects should not be ignored.

There is no longer any doubt that air pollution has harmful effects on public health. The terrible episodes of the middle of the last century in London

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<sup>1</sup> A micron is one one-thousandth of a millimetre.



(England), Donora, Pennsylvania (United States) and the Meuse Valley (Belgium) left no room for doubt that high levels of pollution can have deleterious effects, including increased mortality in the exposed population. Numerous epidemiological studies conducted in the last 30 years have shown that current levels of pollution also have adverse effects. The Environmental Protection Agency in the United States (USEPA) and the World Health Organization (WHO) are constantly carrying out analyses and studies to quantify the health damage caused by air pollution.

Contaminants produce a great variety of health effects; the principal ones are shown in table VI.1, which sums up current knowledge. An excellent review of the state of the art with respect to the impacts of atmospheric contaminants on health can be found in Holgate et al (1999).

Table VI.1  
**HEALTH PROBLEMS WITH GREATER INCIDENCE CAUSED  
BY ATMOSPHERIC CONTAMINANTS**

Quantifiable effects	Unquantifiable effects
Mortality (older adults)	Inducement of asthma
Mortality (infant)	Effects on fetal/neonatal development
Neonatal mortality	Greater sensitivity of respiratory tract
Bronchitis - chronic and acute	Chronic respiratory illnesses (other than bronchitis)
Asthma attacks	Cancer
Hospital admissions (respiratory and cardiovascular)	Lung cancer
Emergency room visits	Behavioural effects
Respiratory illnesses (upper and lower)	Neurological disorders
Respiratory symptoms	Exacerbation of allergies
Days missed from work	Alteration of defence mechanisms
Days of restricted activity	Damage to respiratory cells
	Less time for development of angina
	Morphological changes in lungs
	Cardiovascular arrhythmia

**Source:** Adapted from the United States Environmental Protection Agency (EPA), "The Benefits and Costs of the Clean Air Act, 1990 to 2010", Final Report to Congress, EPA-410-R-99-001, Washington, D.C., 1999.

### 3. Global contaminants and their effect

The main global contaminants are the so-called greenhouse gases (GHG). The most important ones are carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O) and tropospheric ozone (O<sub>3</sub>). These gases trap infrared radiation re-emitted to space by the earth, so an increase in their concentration causes the atmosphere to heat up (PICC, 2001). The result is an increase in extreme weather phenomena and other climatic consequences. These gases have a long life and are distributed throughout the atmosphere, so their effect does not depend on the place where they are emitted.

## B. INCIDENCE OF VEHICLE TRAFFIC ON POLLUTION

### 1. Types of contaminants emitted by vehicles

Motor vehicles are one of the principal sources of atmospheric contaminants in large cities. Motor vehicles that operate on internal combustion engines produce three types of contaminant emissions, in general: exhaust pipe emissions, evaporative emissions, and dust raised from the street (see table VI.2).

Table VI.2  
**PRINCIPAL CONTAMINANTS EMITTED BY MOTOR VEHICLES**

Type of emission	Primary contaminants emitted into the atmosphere
Through exhaust pipe	CO, NO <sub>x</sub> , SO <sub>2</sub> , HC, Pb (leaded gasolines), NH <sub>3</sub> (especially gasoline vehicles with catalytic converters), CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O, MP (diesel vehicles only)
Evaporative	HC (hydrocarbons)
Raised street dust	Street dust (material from the earth's crust plus contaminants deposited there)

**Source:** Internal compilation.

CO = carbon monoxide; NO<sub>x</sub> = nitric oxides; SO<sub>2</sub> = sulphur dioxide; HC = hydrocarbons; Pb = lead; NH<sub>3</sub> = ammonia; CO<sub>2</sub> = carbon dioxide; CH<sub>4</sub> = methane; N<sub>2</sub>O = nitrous oxide; PM = particulate matter.

#### (a) Exhaust pipe emissions

Emissions from the exhaust pipe are the product of fuel combustion (whether the fuel is gasoline, diesel, or another petroleum derivative). Because the combustion is not perfect, a number of contaminants are produced, such as carbon monoxide and nitrogenous oxides. In addition, certain contaminants present in the fuel, such as lead and sulphur, are released into the atmosphere in the combustion process. Exhaust pipe emissions depend on the characteristics of the vehicle, its technology and the engine size; for example, heavy vehicles tend to have higher unitary emissions (emissions per kilometre travelled) than light vehicles. Emissions also depend on the presence of emission-reducing features such as catalytic converters; on the vehicle's maintenance status; on operational factors, such as speed of circulation and level of acceleration; and the characteristics of the fuel, such as sulphur content.

**(b) Evaporative emissions**

Evaporative emissions occur as the fuel evaporates into the atmosphere, and are therefore hydrocarbons (HC). Their amount depends on the characteristics of the vehicle, operational factors such as the number and frequency of stops, geographic and meteorological factors such as altitude and environmental temperature, and most importantly, the steam pressure of the fuel.

**(c) Raised dust**

Emissions caused by raising street dust depend on the weight of the vehicle and its circulation speed, and on the characteristics of the street, such as the average flow of vehicles on it. They also depend, of course, on the amount of solid matter deposited on the streets that is likely to be raised by vehicles. Unlike the particulate matter emitted by diesel vehicles' exhaust pipes, that raised by the circulation of vehicles is primarily inert matter from the earth's crust (dust), which can also contain other contaminants that have been deposited after being emitted into the atmosphere. The composition of this particulate matter will thus depend on what city or place it is located in.

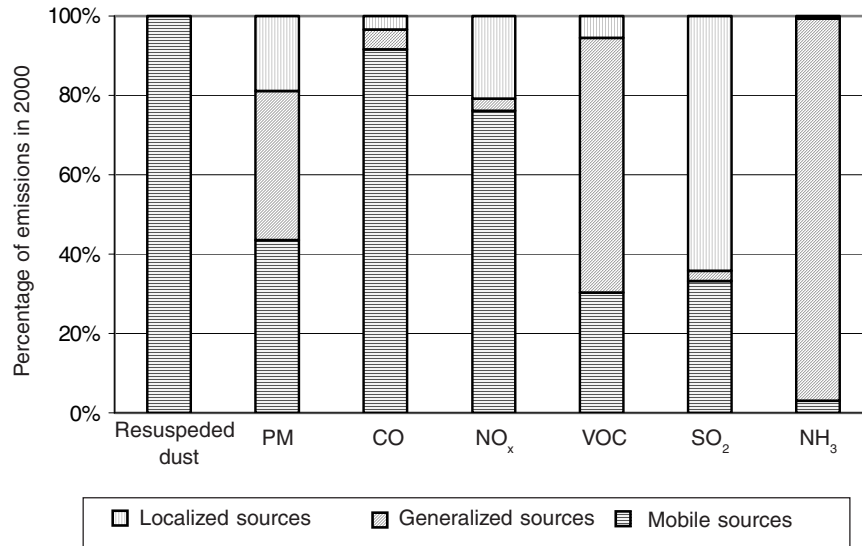
**(d) Secondary contaminants**

It is also necessary to emphasize that primary contaminants emitted into the atmosphere can react there, forming so-called secondary contaminants. The most important of these are secondary particulate matter (which is part of fine particulate matter or PM<sub>2.5</sub>) and ozone. In Santiago, it is estimated that more than 60% of the fine particulate matter is secondary matter (CONAMA, 2001a).

**2. Relative importance of vehicle-generated contaminants**

Vehicles generate a major part of the emissions in a city, the exact amount depending on multiple local factors. By way of example, figure VI.1 depicts the situation in Santiago in 2000, and shows that mobile sources account for a significant percentage of primary contaminant emissions.

Figure VI.1  
INCIDENCE OF MOBILE SOURCES ON CONTAMINANT EMISSIONS  
IN THE SANTIAGO METROPOLITAN REGION



**Source:** Internal compilation based on the emissions inventory of the National Center for the Environment (CENMA), Mejoramiento del Inventario de Emisiones de la Región Metropolitana, Santiago, Chile, August 2000.

PM = particulate matter; CO = carbon monoxide; NO<sub>x</sub> = nitrogenous oxides;  
VOC = volatile organic compounds; SO<sub>2</sub> - sulphur dioxide; NH<sub>3</sub> = ammonia

Furthermore, it is estimated that in 2000 mobile sources were responsible for approximately 48% of the fine particulate matter present in the atmosphere, of which buses were estimated to have contributed 21%, trucks 12% and light vehicles 15% (CONAMA, 2001a).

### 3. One way to estimate the amount of contaminants emitted by vehicles

In general, all internal combustion vehicles produce contaminant emissions as a result of combustion. As was noted earlier, the amount of the emissions depends on the characteristics of the vehicle and its operation. The emissions of interest here are those coming from the entire fleet of vehicles operating in a city, which can be described in a simplified manner using the following formula:

$$E^c = \sum_{m=1}^M [FE_m^c(V_m) \cdot DT_m]$$

In which:

$E^c$  are the total emissions of a certain contaminant  $C$  (for example,  $\text{NO}_x$ ,  $\text{CO}$ ,  $\text{HC}$ )

$m$  are the modes of transportation operating in a city (car, bus, taxi or others)

$EF(S_m)$  is the so-called "emission factor" of contaminant  $C$ , corresponding to the mode (type of vehicle)  $m$ . In other words, it is the amount of contaminant  $C$  that each type of vehicle emits when it travels one kilometre.

$S_m$  is the speed at which the vehicles of mode  $m$  are circulating.

$DT_m$  is the total distance travelled by mode  $m$  for a certain period.

In general, emission factors are measured in grams per kilometre travelled, distance in kilometres per day, and total emissions in kilograms or tons per day.

The formula indicates that the total amount of each contaminant is calculated as the sum of the contaminants produced by each type of vehicle. These, in turn, are calculated by taking the amount each type of vehicle emits per kilometre, depending on the speed at which it is travelling, and multiplying that by the total number of kilometres travelled.

### **C. EFFECTS OF REDUCED CONGESTION ON POLLUTION**

When measures are taken to combat congestion, the primary impact is a change in the speeds at which different modes of transportation travel. Analysing the emissions formula and its derivations as a function of the variation in speed, two simultaneous effects on emissions can be seen:

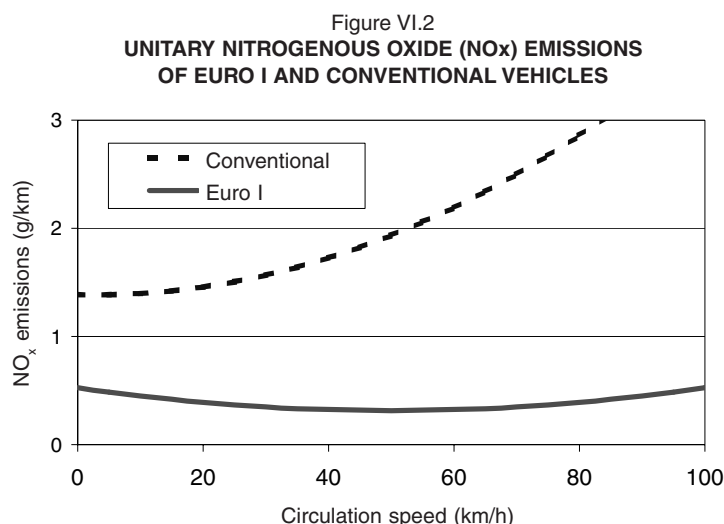
- The mode's emission factor changes because of the change in its operating speed, and
- The distance travelled by each mode changes.

#### **1. Change in emission factors caused by change in speed of travel**

The emission factor, or the amount of contaminants emitted per kilometre by each type of vehicle, depends on the vehicle's technology, and it varies according to the speed of circulation (figures VI.2 and VI.3). The emission factor also depends on the vehicles' acceleration, which in turn is related to the speed and the driving cycle.

The vehicle's technology is the way it treats emissions, which determines the amount of them. In this context, the Euro standards established by the European Union are important. Euro I prevailed in Europe until 1996, and compliance with it generally required a three-way catalytic converter. That

year it was replaced by Euro II, which in turn was replaced in 2000 by the more stringent Euro III, now in effect. In the United States, heavy vehicles were required to meet the EPA91, EPA94 and EPA98 standards, similar to Euro I, II and III, respectively. There is no emission control system for conventional vehicles.



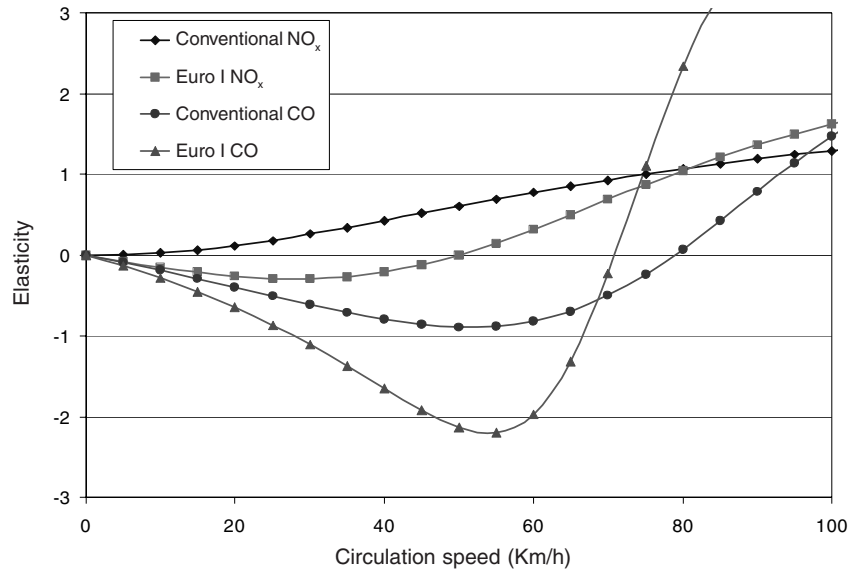
**Source:** Internal compilation based on European Environment Agency (EEA), 2000, "COPERT III Computer Programme to Calculate Emissions from Road Transport - Methodology and Emission Factors", Technical Report, No. 49 ([http://reports.eea.eu.int/Technical\\_report\\_No\\_49/en](http://reports.eea.eu.int/Technical_report_No_49/en)), 2000.

It can be seen that in the case of a vehicle complying with the Euro I standard, as it increases speed emissions decline because the vehicle is operating more efficiently. However, after a certain speed, which for nitrogenous oxide is approximately 50 km/h, emissions begin to increase because it takes more energy to move the vehicle at higher speeds. For a conventional vehicle, emissions always increase with speed.

In this manner, if a measure to reduce congestion translates into a rise in operating speed, there is a decline in the emissions of catalytic converter vehicles because of the speed effect, as long as the speed is below the point at which emissions begin to climb. This condition almost always occurs in an urban area. For example, the average speed of private vehicles circulating in Santiago is 26 km/h during morning rush hour. Depending on the composition of technologies of the vehicle fleet and average circulation speeds, a measure reducing congestion will either lower or raise nitrogenous oxide emissions.

The unitary emissions resulting from the speed of circulation varies according to the contaminant and the technology. In general, for all contaminants of interest, emissions fall as the speed of travel rises (see figure VI.3).

Figure VI.3  
**UNITARY VARIATION IN EMISSIONS AS A FUNCTION  
 OF VEHICLE SPEED AND TECHNOLOGY**



**Source:** Internal compilation based on European Environment Agency (EEA), 2000, "COPERT III Computer Programme to Calculate Emissions from Road Transport - Methodology and Emission Factors", Technical Report, No. 49 ([http://reports.eea.eu.int/Technical\\_report\\_No\\_49/en](http://reports.eea.eu.int/Technical_report_No_49/en)), 2000.

No<sub>x</sub> = nitrogenous oxides  
 CO = carbon monoxide

Elasticity is the percentage change in emissions when circulation speed varies by 1%. The negative values indicate that emissions decrease as speed increases, and vice-versa.

It can be seen that for carbon monoxide, up to a certain speed emissions decrease as speed increases. This situation reverses at 70 or 80 km/h, depending on whether the vehicle is conventional or Euro I. It is therefore unlikely that a measure reducing congestion could increase emissions. Nevertheless, for nitrogenous oxides the situation is different, as noted above and as corroborated in this figure.

## 2. Change in distance travelled for each mode

The second effect of a measure aimed at reducing congestion is a variation in the total distance travelled by each mode of transportation, due to the fact that some travellers change the mode they use. In this case, whether total emissions rise or fall will depend largely on the type of measure. If the distance

travelled increases for the less polluting modes of transportation, the measure will lower total emissions, and vice-versa.

As shown in chapters III and IV, the measures designed to ease congestion can be classified according to whether they act on supply or demand. In general, measures that modify supply by favouring the use of cars, such as redesigning, widening or building new roads and express lanes, can lead to an increase in the distance travelled by that means. This would lead to higher emissions from that source, and possibly higher total emissions. Conversely, measures that reduce the demand for car travel, such as road pricing in the short term, may result in smaller distances travelled by that means, and thus a decline in total emissions.

### **3. Change in fuel consumption**

Changing the speed of circulation and the total distance travelled for each mode of transportation also has an impact on the total consumption of each type of fuel. Emissions of some contaminants, such as CO<sub>2</sub>, sulphur and lead, depend directly on the consumption of fuels containing them, so their emission levels change proportionally.

## **D. RESULTS OF SOME ANTI-CONGESTION MEASURES STUDIED IN SANTIAGO**

Chapter V reported on the study that examined several measures designed to reduce congestion in Santiago using the ESTR AUS and VERDI Models. For some of these measures, the effect of their implementation on the emission of contaminants was analysed, and the results of that analysis are presented here.

### **1. Description of the measures analysed**

Three road pricing measures with different degrees of coverage and tolls were analysed, as was the introduction of executive buses:

- Pricing C1000: collecting a toll of 1,000 pesos for entering the area comprising the city centre and the area surrounding Avenida Providencia.
- Pricing AV1000: collecting a toll of 1,000 pesos for entering the area within the Américo Vespucio Beltway. This area includes most of the populated territory of the city.
- Combination SE+AV2000: establishing segregated lanes for public transit vehicles and collecting a toll of 2,000 pesos to enter the area within the Américo Vespucio Beltway.
- ExecBus2: introducing a service with high-quality 40-passenger buses passing by five times an hour.

The specific details of these measures can be found in chapter V.



## **2. The MODEM Model for calculating emissions**

The MODEM Model is a computer program commissioned by the Ministry of Planning and Cooperation (MIDEPLAN) that makes it possible to calculate emissions of atmospheric contaminants by mobile sources. Using as input the traffic volume and speed data supplied by the ESTRAUS Model, this model calculates the contaminant emissions generated by each mode of transportation. More details on the MODEM Model can be found in University of Chile (2000).

### **(a) Contaminants considered**

The contaminants considered by MODEM are carbon monoxide (CO), total hydrocarbons (THC), nitrogenous oxides (NO<sub>x</sub>), ammonia (NH<sub>3</sub>) and breathable particulate matter (PM). Estimates of the greenhouse gases nitrous oxide (N<sub>2</sub>O) and methane (CH<sub>4</sub>) are also included.

Carbon dioxide (CO<sub>2</sub>) emissions were estimated on the basis of fuel consumption, using the emission factors proposed by COPERT (EEA, 2000). Sulphur dioxide (SO<sub>2</sub>) emissions were determined by simply analysing the sulphur content of the diesel fuel consumed in Santiago. At present, the content is 300 parts per million, which is low, considering that in some cities in Latin America it can be as high as 1,000 or more parts per million. Lead emissions were not considered because no leaded gasoline has been sold in Santiago since 2000.

The change in emissions of resuspended street dust was not calculated. In any case, as shown in table VI.8, the impact of this dust on the population's well-being is considerably smaller than that of emissions of other contaminants.

### **(b) Types of vehicle considered**

In the analysis, vehicles are divided into 18 categories, according to their type and emission standard. The table below shows the types of vehicles considered.

Table VI.3  
**CATEGORIES OF VEHICLE CONSIDERED BY THE MODEM MODEL**

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Public transit buses with no emission controls
EPA91 or Euro I public transit buses
EPA94 or Euro II public transit buses
Intercity buses
Pullman buses
Double-axle trucks
Trucks with more than two axles
Light commercial vehicles with catalytic converters
Light commercial vehicles without catalytic converters
Light commercial diesel vehicles
Regular taxis with catalytic converters
Regular taxis without catalytic converters
Collective taxis with catalytic converters
Collective taxis without catalytic converters
Cars with catalytic converters
Cars without catalytic converters
Motorcycles with two-cycle engines
Motorcycles with four-cycle engines

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**Source:** Departamento de Ingeniería Mecánica, "MODEM, Informe final", report prepared for the Ministry of Planning and Cooperation (MIDEPLAN), Santiago, Chile, University of Chile, January 2000.

In other words, the same types of vehicles are considered as with the ESTRAUS Model, but differentiated by emission technology.

Public transit buses have a capacity for approximately 35 to 40 seated passengers. Three technologies, the EPA91 (or Euro I) and EPA94 (or Euro II) standards, plus buses without any emission controls, are considered. In Chile, the Euro III standard has been in effect for new buses since September 2002, but the existing fleet of buses is made up of vehicles with other technologies.

No distinction is made for technology in the case of trucks and intercity buses.

Commercial vehicles are medium-sized vehicles such as pickup trucks and vans, with a weight of no more than 3.5 tons. No distinction is made for emission reduction technology in the case of diesel vehicles because of the small number of them; this situation is changing in Chile, however, because of the steady rise in the price of fuel.

Although there is a substantial fleet of conventional cars, all those sold in the Metropolitan Region of Santiago since 1992 must meet the Tier 0 emission standard (the U.S. standard), which in practice requires the use of a three-way catalytic converter (as is the case for Euro I). Beginning in 2003, light vehicles must meet the Tier 1 standard, which is even stricter, although as of September 2001 more than 90% of new catalytic-converter vehicles met that standard.

The relative composition of vehicle types has changed over time. For example, as was mentioned previously, beginning in September 2002 buses in Santiago must meet the EPA98 standard (Euro III), so this category should be incorporated into the model along with the Tier I light vehicles.

### **(c) Calculations made by MODEM**

The MODEM Model calculates emissions produced on every stretch of the transportation network, taking into account all categories of vehicles circulating there. Total emissions of a given contaminant are obtained by adding up those produced on all segments of motorway, using hourly, daily and yearly periods.

The calculations cover all of Greater Santiago, although the model can yield results differentiated by zones within the city. Other results are also provided, such as consumption levels of different fuels and the density of traffic flows. These can be compared with those from other sources, such as regional fuel consumption statistics, to check the results.

The emission factors used by the model have been developed on the basis of the European emission factors proposed in COPERT II and III (EEA, 2000) and Chilean experiments with light vehicles at the Center for Vehicle Control and Certification of the Chilean Ministry of Transport. Emission factors take into account the speed of travel for each arc with a correction for acceleration, which depends on the speed of travel.

## **3. Changes in emissions upon implementation of anti-congestion measures**

The results of the ESTRAUS Model for the four measures enumerated above are discussed in chapter V. They were used by the MODEM Model to calculate the changes that would occur in contaminant emissions if these measures were implemented. The results obtained are presented below.

### **(a) Change in emissions resulting from road pricing measures**

With a few exceptions, the road pricing measures have positive effects on emissions. Road pricing makes it more expensive to travel by car, which prompts drivers to switch to other modes such as the bus. As one might expect, the most significant reductions in emissions are obtained when the highest tolls are applied to the largest geographical areas (see tables VI.4 and VI.6). As the scope grows larger (SE+AV2000), the proportion of private vehicles (cars and taxis) drops by nearly 2.2%; a notable improvement in bus travel times is also seen, with an average reduction of 5.5 minutes. This translates into major decreases in the consumption of time and in traffic on the network, which definitely reduces emissions of all contaminants.

Table VI.4  
**SANTIAGO: EMISSION CHANGES IN TONS PER YEAR WITH THE INTRODUCTION  
 OF SEGREGATED BUS LANES AND A TOLL OF 2,000 PESOS  
 FOR CROSSING THE AMÉRICO VESPUCCIO BELTWAY**

Type of vehicle	Contaminant								
	PM	CO	HC	NO <sub>x</sub>	SO <sub>2</sub>	NH <sub>3</sub>	CO <sub>2</sub>	N <sub>2</sub> O	CH <sub>4</sub>
Public transit buses	-48	-251	-154	-500	-5.8	0.0	-30 077	0.0	0.0
Intercity buses	-9	-43	-21	-99	-1.0	0.0	-5 363	0.0	0.0
Trucks	-108	-435	-287	-1 129	-14.7	-0.2	-77 034	-2.3	-7.9
Cars	0	-14 827	-856	-924	0.0	-28.3	-214 463	-21.4	-81.6
Taxis	0	-2 479	-146	-183	0.0	-11.6	-65 741	-8.4	-19.7
Commercial vehicles	-15	-4 435	-476	-372	0.0	-8.7	-138 307	-2.9	-32.9
Motorcycles	0	-382	-127	-1	0.0	-0.1	-2 980	-0.1	-3.0
<b>Total</b>	<b>-180</b>	<b>-22 851</b>	<b>-2 068</b>	<b>-3 208</b>	<b>-21.5</b>	<b>-48.9</b>	<b>-533 966</b>	<b>-35.1</b>	<b>-145.1</b>
<b>Total (%)</b>	<b>-11</b>	<b>-18</b>	<b>-16</b>	<b>-10</b>	<b>-7.1</b>	<b>-12</b>	<b>-12.6</b>	<b>-11</b>	<b>-13</b>

**Source:** Internal compilation based on results obtained from processing with MODEM Model.  
 PM = particulate matter; CO = carbon monoxide; HC = hydrocarbons; NO<sub>x</sub> = nitric oxides;  
 SO<sub>2</sub> = sulphur dioxide; NH<sub>3</sub> = ammonia; CO<sub>2</sub> = carbon dioxide; N<sub>2</sub>O = nitrous oxide; CH<sub>4</sub> = methane.

This measure would bring about a reduction of 18% in CO emissions, mainly due to the lighter traffic in cars, which would give off 14,827 tons less per year. Another important result is the 10% cut in NO<sub>x</sub> emissions stemming from major declines in truck traffic (1,129 tons less per year) and car traffic (924 tons less per year).

#### (b) Change in emissions resulting from introduction of executive buses

This measure causes an increase in total emissions, which is attributable to the longer travel times of nearly all modes as the new buses enter the flow of traffic. The exception is regular buses, but their lower emissions do not offset the other modes' higher emissions.

Table VI.5  
**SANTIAGO: EMISSION CHANGES IN TONS PER YEAR DUE TO  
 INTRODUCTION OF EXECUTIVE BUSES**

Type of vehicle	Contaminants								
	PM	CO	HC	NO <sub>x</sub>	SO <sub>2</sub>	NH <sub>3</sub>	CO <sub>2</sub>	N <sub>2</sub> O	CH <sub>4</sub>
Public transit buses <sup>a</sup>	-3.1	-16.3	-14.2	-24.5	-0.2	0.0	-1 295	0.0	0.0
Intercity buses	0.6	2.6	0.9	6.4	0.1	0.0	360	0.0	0.0
Trucks	16.9	66.7	45.2	175.2	2.3	0.0	11 816	0.3	1.1
Private cars	0.0	1 838.5	93.9	90.0	0.0	2.6	21 731	2.0	9.1
Taxis	0.0	302.4	16.4	20.4	0.0	1.3	6 997	0.9	2.1
Commercial vehicles	1.7	574.1	59.7	44.2	0.0	1.1	16 344	0.4	3.9
Motorcycles	0.0	46.7	16.0	0.2	0.0	0.0	369	0.0	0.4
<b>Total</b>	<b>16.1</b>	<b>2 815</b>	<b>218</b>	<b>312</b>	<b>2.1</b>	<b>5.0</b>	<b>56 322</b>	<b>3.6</b>	<b>16.6</b>
<b>Total (%)</b>	<b>1.0</b>	<b>2.2</b>	<b>1.7</b>	<b>1.0</b>	<b>0.7</b>	<b>1.2</b>	<b>1.3</b>	<b>1.1</b>	<b>1.5</b>

**Source:** Internal compilation based on results obtained from processing with MODEM Model.  
 PM = particulate matter; CO = carbon monoxide; HC = hydrocarbons; NO<sub>x</sub> = nitric oxides;  
 SO<sub>2</sub> = sulphur dioxide; NH<sub>3</sub> = ammonia; CO<sub>2</sub> = carbon dioxide; N<sub>2</sub>O = nitrous oxide; CH<sub>4</sub> = methane.  
<sup>a</sup> Includes executive buses.

The greatest percentage increase is for CO, at 2.2%, mainly due to the higher CO emissions of cars, taxis and commercial vehicles. The truck sector produces the most significant increase in NO<sub>x</sub> emissions (175 tons/year) and PM (16.9 tons/year).

### (c) Summary of emission changes

Table VI.6 shows the results of emission changes in percentages of the base case. It is worth mentioning that the results presented here do not reflect the long-term effects, such as changing land use as a result of road pricing measures, as commented earlier (chapter IV, section F). It can be observed that the most restrictive road pricing (C1000) also causes a rise in global emissions.

Table VI.6  
**SANTIAGO: PERCENTAGES OF TOTAL EMISSION CHANGES  
FOR EACH MEASURE ANALYSED**

Measure	Local pollutants					Global pollutants			
	PM	CO	HC	NO <sub>x</sub>	SO <sub>2</sub>	NH <sub>3</sub>	CO <sub>2</sub>	N <sub>2</sub> O	CH <sub>4</sub>
C1000	-0.9%	0.7%	0.2%	-0.3%	-0.5%	0.3%	0.4%	0.2%	0.3%
AV1000	-7.2%	-13.0%	-11.7%	-7.0%	-4.7%	-9.4%	-9.3%	-8.5%	-9.4%
SE+AV2000	-11.0%	-17.9%	-16.3%	-9.8%	-7.1%	-11.8%	-12.6%	-10.7%	-11.8%
ExecBus2	1.0%	2.2%	1.7%	1.0%	1.3%	1.2%	1.3%	1.1%	1.2%

Source: Internal compilation based on results obtained from processing with MODEM Model.

PM = particulate matter; CO = carbon monoxide; HC = hydrocarbons; NO<sub>x</sub> = nitric oxides;

SO<sub>2</sub> = sulphur dioxide; NH<sub>3</sub> = ammonia; CO<sub>2</sub> = carbon dioxide; N<sub>2</sub>O = nitrous oxide;

CH<sub>4</sub> = methane.

C1000 = toll of 1,000 for entering city centre and areas surrounding Avenida Providencia;

AV1000 = toll of 1,000 pesos for entering the area encompassed by Avenida A. Vespucio;

SE+AV2000 = segregated lanes plus toll of 2,000 pesos for entering the area encompassed by Avenida A. Vespucio; ExecBus2 = high-quality buses.

## 4. Quantification of health effects resulting from emission changes

It is possible to assign a value to the health effects resulting from changes in the level of pollution caused by the adoption of measures, including those oriented towards reducing congestion. The process involves the following steps:

- Determination of the change in atmospheric concentrations of contaminants as a result of emission changes.
- Determination of the change in effects on the health of the exposed population as a result of changes in the concentration of contaminants in the environment.
- Calculation of the social costs or benefits derived from the change in the effects on the health of the population.

The methodology described below was followed in establishing the value for the city of Santiago, Chile, as part of the studies carried out to evaluate the Prevention and Decontamination Plan of the Santiago Metropolitan Region (CONAMA, 2001b).

**(a) Determination of the change in atmospheric concentrations of contaminants as a result of emission changes**

The change in the concentration of contaminants can be calculated as a function of emission changes using atmospheric models. Another option is to use simplified roll-back models, which assume there is a proportional relationship between atmospheric concentrations in a basin and the contaminant emissions that produce them. A base level not dependent on emissions in the basin can also be assumed.

In the case of Santiago, approximate roll-back models have been used, considering all primary contaminants that help make up the secondary particulate matter, namely, sulphur dioxide, ammonia, nitrogenous oxides, primary particulate matter and resuspended street dust. In the case of ozone, only nitrogenous oxides, which determine the concentrations of that contaminant in Santiago, are considered as precursors.

**(b) Determination of the change in effects on the health of the exposed population as a result of changes in the concentration of contaminants in the environment**

The so-called concentration-response functions correlate changes in atmospheric concentrations of contaminants with the effects they have on the population's health. These functions are obtained from epidemiological studies that measure the effects on an exposed population and compare them with the various effects the same population has experienced over time, or with the effects on other populations exposed to different levels of contamination.

In recent years a great number of these studies have been carried out, making it possible to establish quantitative relationships for many of the effects shown in table VI.1. Although most of the studies were done in the United States or Europe, a growing number of them are taking place in developing countries.

The effects in Santiago were estimated on the basis of concentration-response functions developed in this city for premature mortality and children's visits to emergency rooms. Other functions were taken from the specialized literature, especially the evaluation done by the USEPA (EPA, 1999). The effects considered are premature mortality, hospital admissions, visits to the emergency room, incidence of chronic and acute bronchitis cases, incidents of asthma attacks, missed work and days of restricted activity.

**(c) Unitary values of effects on health**

Society assigns values to health effects, which can be classified as follows:

- Treatment costs, which are the direct costs of medical treatment (for example, for going to and remaining in an emergency room).
- Lost productivity, which is the value of the work not done by the person involved (for example, work days missed due to hospitalization, either for the person involved, if he is employed, or for those who must care for or accompany the sick or hospitalized person).
- Loss of usefulness or well-being from suffering an impact, for example, the unpleasantness of having an asthma attack.

Determining the values for each of the effects is the subject of specific studies. The first two values can be calculated by quantifying the direct costs of the effects, for example, by analysing the medical costs of hospitalization for a certain illness and multiplying the length of hospitalization and the period of convalescence by the daily wages of the person involved.

The value of lost well-being or usefulness can be calculated by means of studies that measure individuals' willingness to pay to lessen the impact of the adverse effects. The most important of these effects is the risk of death. Numerous studies have been carried out to estimate the willingness to pay to reduce this risk. The USEPA analysis (EPA, 1999) covers 26 studies conducted in the United States. For the Santiago estimate, U.S. values were applied to Chile after adjusting for the respective per capita incomes, and were combined with the results of a contingent assessment study carried out in Santiago (see table VI.7).

Table VI.7  
**UNITARY VALUES IN 1997 DOLLARS USED FOR EACH HEALTH  
EFFECT PRODUCED BY ENVIRONMENTAL POLLUTION**

Adverse effect	Age group	Treatment costs	Lost productivity	Lost well-being	Total
Risk of death	All	-	61 166	498 834	560 000
Chronic bronchitis	> 30 years	1 811	39 809	-	41 620
Hospital admission, respiratory	All	958	179	-	1 137
Hospital admission, cardiovascular	All	2 210	236	-	2 446
Emergency room visit, children	3-15 years	33	138	-	170
Emergency room visit, respiratory	All	10	52	-	61
Emergency room visit, pneumonia	< 15 years	127	8	-	135
Emergency room visit, asthma	0-64 years	47	86	-	133
Asthma attack	All	-	-	5.1	5.1
Acute bronchitis	8-12 years	-	-	6.9	6.9
Day with respiratory symptoms	18-64 years	-	-	2.8	2.8
Day of missed work	18-64 years	-	24.1	-	24.1
Day of restricted activity	18-64 years	-	-	5.8	5.8

**Source:** L. Cifuentes, "Estimación de los beneficios sociales de la reducción de emisiones y concentraciones de contaminantes atmosféricos en la Región Metropolitana", Generación de instrumentos de gestión ambiental para la actualización del Plan de Descontaminación Atmosférica para la Región Metropolitana de Santiago al Año 2000, document prepared for the National Environment Commission, Santiago, Chile, Catholic University of Chile (PUC), 2000.

**(d) Calculation of social costs or benefits resulting from a one-ton change in the emission of each contaminant**

Combining the three previous stages, the next step is to calculate the benefit or cost associated with reducing or increasing, respectively, the emission of each of the contaminants of interest by one ton (see table VI.8). It is reasonable to determine a single value for each contaminant, since the changes occur at a level at which most of the functions are linear.

Table VI.8  
**VALUE OF HEALTH EFFECTS RESULTING FROM ONE-TON CHANGE  
IN EMISSION OF A CONTAMINANT**  
*(in thousands of dollars per ton of reduction)*

Primary contaminant	Treatment cost	Lost productivity	Lost well-being	Total
Resuspended dust	0.013	0.14	0.54	0.69
Particulate matter	1.063	11.64	43.2	55.9
Nitrogenous oxides (NO <sub>x</sub> )	0.055	0.60	2.2	2.9
Sulphur dioxide (SO <sub>2</sub> )	0.279	3.05	11.3	14.7
Ammonia (NH <sub>3</sub> )	0.077	0.85	3.2	4.1

**Source:** Comisión Nacional del Medio Ambiente, *Análisis general del impacto económico y social del anteproyecto de Plan de Prevención y Descontaminación de la Región Metropolitana*, Santiago, Chile, August 2001; and L. Cifuentes, "Estimación de los beneficios sociales de la reducción de emisiones y concentraciones de contaminantes atmosféricos en la Región Metropolitana", *Generación de instrumentos de gestión ambiental para la actualización del Plan de Descontaminación Atmosférica para la Región Metropolitana de Santiago al Año 2000*, document prepared for the National Environment Commission (CONAMA), Santiago, Chile, Catholic University of Chile (PUC), 2000.

It is evident that the contaminant with the greatest value per ton of reduction is particulate matter, followed by sulphur dioxide and ammonia. Of the total value, treatment costs represent about 2%, lost productivity 21%, and the rest –the largest proportion– corresponds to lost well-being. That, in turn, is dominated by the population's willingness to pay to reduce its risk of death. It should be emphasized that these are average values.

**(e) Values per ton of reduction of greenhouse gases**

Although developing countries have not made any commitment to reduce greenhouse gases, they have an option to assign a value to them on the basis of the "Clean Development Mechanism" included in the Kyoto Protocol. This allows for the sale of "carbon bonds" to countries that are under an obligation to reduce these gases. The market is not fully developed yet, but institutions such as the Prototype Carbon Fund (PCF), created by the World Bank, have purchased carbon reductions from emission-cutting projects. For



example, in the Chacabuquito Project<sup>2</sup> in Chile, the PCF recently bought reductions at a price of US \$3.50 for the reduction of each ton of CO<sub>2</sub> equivalent.<sup>3</sup> In the future, as the demand for CO<sub>2</sub> reductions increases, this price should rise. Based on these considerations, reductions of greenhouse gases were valued at US \$3.50 and \$10.00 per ton of CO<sub>2</sub> equivalent.

**(f) Calculation of variation in well-being resulting from change in pollution produced by anti-congestion measures. Comparison with benefits they yield for the transport system**

The last step is to determine the change in social well-being due to the variation in the impact on health, multiplying the changes in tons reduced that each measure brings about by the corresponding monetary values (see table VI.9). If the health costs diminish, there is a benefit, and vice-versa. The table also shows the positive or negative effects of the same measures on the transport system as such, for comparative purposes.

Table VI.9  
**SANTIAGO: SOCIAL BENEFITS FOR TRANSPORT AND POLLUTION  
CORRESPONDING TO ANTI-CONGESTION MEASURES ANALYSED**  
(In millions of dollars per year)

Measure	Transport benefits		Local contaminant benefits		Global contaminant benefits	
	Direct	Total	Direct	Total	@ 3.5 <sup>a</sup> US\$/tCO <sub>2</sub> e <sup>c</sup>	@ 10 <sup>b</sup> US\$/tCO <sub>2</sub> e <sup>c</sup>
C1000 <sup>d</sup>	3.26	-107.45	0.26	1.14	-0.05	-0.15
AV1000 <sup>e</sup>	24.81	-289.14	3.14	13.64	1.38	3.95
SE+AV2000 <sup>f</sup>	45.79	-284.69	4.57	19.87	1.87	5.34
ExecBus2 <sup>g</sup>	N/A	N/A	-0.42	-1.85	-0.20	-0.56

**Source:** Internal calculations based on results from VERDI and MODEM Models.

<sup>a</sup> At a rate of US \$3.50

<sup>b</sup> At a rate of US \$10.00

<sup>c</sup> Dollars per ton of CO<sub>2</sub> equivalent

<sup>d</sup> Toll of 1,000 pesos for entering city centre and area surrounding Avenida Providencia

<sup>e</sup> Toll of 1,000 pesos for crossing Avenida A. Vespucio

<sup>f</sup> Segregated lanes combined with toll of 2,000 pesos for entering the area defined by Avenida A. Vespucio

<sup>g</sup> High-quality buses

Both types of benefit have been divided into direct and total. In the case of transport, the benefits were calculated using the VERDI Model (see chapter V, section B). Direct benefits are those corresponding to resource savings (savings in operating costs and time); total benefits are calculated according

<sup>2</sup> See details at the Fund website (<http://www.prototypecarbonfund.com>).

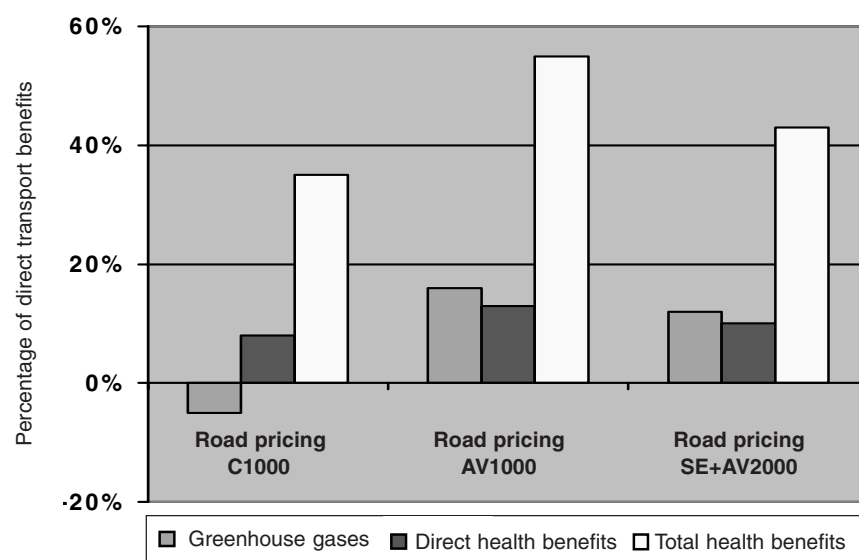
<sup>3</sup> CO<sub>2</sub> equivalent includes not only CO<sub>2</sub> but also other greenhouse gases, duly weighted for their global warming potential (GWP). In this case, methane, with a GWP of 21, and nitrous oxide, with a GWP of 310, were considered. Both values were suggested by PICC (2001).

to the traveller benefit method, and include changes in usefulness or surpluses enjoyed by users of the transport system in addition to the two indicated effects. In the case of pollution, direct benefits include the benefits from treatment costs and productivity losses, while total benefits also include the willingness of Santiago residents to pay to avoid adverse health effects.

It can be observed that the road pricing measures analysed are generally positive from the standpoint of pollution, while the opposite is true of large executive buses, which are not good for reducing congestion, either (see chapter V, section C.2). The road pricing schemes taken into consideration yield positive direct benefits to the transport system, but they become negative if benefits to travellers are included, primarily due to the loss of usefulness for those switching to another mode of transportation.

The results show that the benefits of reducing pollution represent an additional benefit beyond the direct benefits to transport, equivalent to 8% to 13% of them. Total benefits, including the willingness to pay to avoid health problems, represent between 35% and 55% of direct benefits to the transport system (see figure VI.4). A comparison with total transport benefits is not rational, since these are negative for the measures analysed.

Figure VI.4  
**SANTIAGO: ENVIRONMENTAL SOCIAL BENEFITS OF ROAD PRICING MEASURES,  
AS A PERCENTAGE OF DIRECT TRANSPORT BENEFITS**



**Source:** Internal compilation based on results from VERDI and MODEM Models.  
C1000 Toll of 1,000 pesos for entering city centre and area surrounding Avenida Providencia  
AV1000 Toll of 1,000 pesos for entering the area defined by Avenida A. Vespucio  
SE+AV2000 Segregated bus lanes combined with toll of 2,000 pesos for entering the area defined by Avenida A. Vespucio.

**Note:** The reduction in greenhouse gases is valued at US \$10.00 per ton of CO<sub>2</sub> equivalent.

## **E. CONCLUSIONS**

Measures designed to ease congestion affect the entire transport system, which in the majority of cities throughout the world is one of the main culprits responsible for air pollution. It is to be expected, then, that a measure aimed at reducing congestion will also have effects on emissions of atmospheric contaminants.

In this chapter, the effects of four anti-congestion measures on the emissions of the transport system in the city of Santiago have been shown. The results indicate that the reduction in emissions depends on the type of measure. When demand is acted upon by means of road pricing, emissions of the transport system are cut, at least in the short term. This has major social benefits, but the transport system itself benefits even more. The introduction of a new mode of transportation, 40-passenger executive buses, increases total emissions in the system, with a net social cost or harm.

Although this analysis has been carried out for Santiago, which is a highly polluted city and where the transport sector accounts for approximately 50% of environmental concentrations of fine particulate matter, the results can serve as a point of reference for other Latin American cities that have air pollution problems in addition to congestion problems. The results suggest that the effects of pollution should be considered when a cost-benefit analysis of transportation measures is undertaken. An integrated strategy for attacking these two problems can lead to more efficient solutions than the application of isolated for combating each of them separately.



## Chapter VII

### CONCLUSION

#### **1. Many travellers prefer congestion to leaving their cars at home**

Traffic congestion has been gaining ground throughout the world, whether developed or not, and all indications are that it will continue worsening, posing a real threat to the quality of urban life. The explosive growth in the number of cars and the indiscriminate desire to use them, for reasons of convenience and status, especially in developing countries, are exerting increasingly strong pressure on the capacity of roads to accommodate them.

The situation does not, however, appear to have been perceived as a major problem by broad sectors of the population in developing countries, or even by the authorities. In opinion surveys, congestion, when it appears at all, is low on the list of concerns. Normally unemployment, crime, the quality of public health and education, poverty and other problems are attributed greater importance. In undeveloped countries in particular, car owners have a strong desire to use them and are willing to endure the congestion that affects them; people who do not yet have cars hope to have one someday. Beyond the oft-repeated statements that congestion is annoying and the authorities should be more diligent in combating it by building more roads, there is no major evidence of any despair or intolerance of it. One of the few manifestations is the use of helicopters to travel around in São Paulo, Brazil, an option limited to people of very high income.

When it comes to commuting to work or school, not many people voluntarily leave their cars at home unless they encounter serious parking problems. The car undoubtedly offers much greater personal mobility and a sense of security, which explains why it is so popular. Preference surveys reveal that this mode of transportation is favoured far and above others. For this reason, current levels of congestion have not managed to alter the balance each individual attains in his own life, which clearly gives the advantage to driving the car even if there are public transit alternatives along the same route on separate thoroughfares that are not congested. From the individual's perspective congestion is an irritating problem, but one that costs less than going on foot.

It is obvious that the car is so advantageous that travellers are willing to tolerate a certain level of congestion, though this level has not been quantified. Thus, it is not necessary or possible to eliminate car travel altogether, but it must be kept under control. Attempts to exert such control should not, however, entail higher costs than those imposed by congestion itself.

## **2. Begin with supply-side measures**

Measures that act on supply, which do not involve expanding the space dedicated to motorways in consolidated urban areas, are generally welcomed, since they represent increases in transport capacity and often do not impose any direct cost on travellers. It remains to be seen how Latin Americans will react to measures for which a fee is charged, such as urban thoroughfares operated by concession, and whether investors will be able to recoup their investment.

It is taken for granted, and often explicitly stated, that the authorities should always provide more and better road infrastructure because of the taxes paid by travellers. This argument is understandable, as the authorities do have an obligation to administer resources appropriately and pursue the common good, which includes dealing with congestion. On the other hand, it is not logical to do so only by building more and more roads, since that does not provide an efficient, stable and environmentally sustainable solution to the problems observed. Moreover, widespread construction of under- and overpasses and highways in urban areas can become counterproductive in the medium and long terms and aggravate congestion. Hence the importance of considering the urban and social impact of actions on infrastructure. It is no less important for citizens and motorists to understand this point.

Furthermore, the authorities should pay attention to other factors that also contribute to the common good, such as maintaining high standards for quality of life while pursuing urban development. Among other things, this implies guaranteeing space for pedestrians and strollers and preserving the city's architectural heritage. Spending should also be prioritized appropriately, which ultimately means that endless roadway expansions are not advisable in view of the fact that in consolidated urban areas road building can be very complicated and burdensome. It also causes a deterioration of the quality of life in the areas where the construction takes place, even if the new transport infrastructure favours more distant areas.

Urban motorways have many deficiencies today, and they must be corrected. Considering the authorities' obligations, it is logical for them to begin the fight against congestion with actions such as improving the design of intersections, marking streets appropriately, rationalizing signposting and correcting the timing of traffic lights. They can also open lanes now used for parking and implement reversible-flow lanes on heavily travelled arteries during rush hour. These measures can do a lot to relieve congestion, and they

are generally low in cost, the main requirement being an understanding of the principles of traffic engineering. Of course, building new roads and widening existing ones should not be ruled out where appropriate and feasible, in the context of harmonious urban development.

Advances in technology open up more possibilities for providing better solutions and more appropriate and reliable designs, and as a result there are new alternatives for acting on transport demand.

Major savings can be achieved by managing traffic signals from a central computer. Although it yields great benefits, for many municipalities this system is not inexpensive; it can be implemented in stages or by sectors of the city, however, perhaps beginning by gradually replacing obsolete traffic lights with signals that support the necessary technology. Obviously perseverance is required to achieve the goal, which is not always assured beyond the term of office of the competent authorities, although applying these measures in heavily travelled areas would yield visible benefits and win citizen support.

Another real need is to organize a public transit system that provides effective service. Important benefits for both buses and cars can be derived from segregated lanes for mass transit. It may be necessary also to reorganize lines into trunk and feeder lines, establish certain circulation preferences and improve the quality of buses and the business capacity of transit companies. High-quality buses can also play a role, especially if their frequencies and hours of operation allow them to serve as a viable alternative for motorists.

A significant contribution can be made by transport systems that resemble a surface subway, organized on the basis of buses that circulate on separate, dedicated thoroughfares at regular intervals under centralized control, with passengers boarding and alighting at stations where they buy tickets in advance. Although they are complicated to implement and certainly require an infusion of public funds to build, the excellent results achieved in the Curitiba programme, the Quito trolleybus and the Bogotá Transmilenio attest to the value of these systems. Their cost is a fraction of that required to build a subway.

It is not certain that the aforementioned measures would attract many motorists to public transit, or to a subway, but there is hope that the proportion of daily trips on this mode of transportation can be maintained and that high-quality, fast service can be offered. This is important in developing countries, since more than half of all trips, even as many as 80% in some cities, are made on mass transit.

Properly designed and executed supply-side measures show interesting potential for coping with congestion. All things considered, it should not be forgotten that better use of supply alone does not address the complex realities associated with congestion. Other measures, particularly demand-side measures, must be incorporated to correct disparities in infrastructure use and achieve an acceptable balance for the community.

### 3. Demand-side measures also have a place

Measures that act on demand are intended to persuade a significant proportion of travellers to switch from cars to high occupancy modes of transportation or travel by non-motorized means during hours of peak traffic, or to change the times of their travel. These measures are either viewed less favourably by motorists or are downright unpopular, since they run counter to people's strong desire to travel on their own. They tend to be supported however, by public transit users, who form the majority in most cities in the region. It is clear that such measures do have a role to play in easing congestion.

Some measures are regulatory in nature and impose restrictions. Others provide economic rewards or disincentives to encourage behaviours that mitigate congestion. Both types should be considered in order to achieve a better overall result, in view of the fact that economic measures may not be totally effective and regulatory measures are vulnerable if enforcement is weak.

Important achievements can be made by rationalizing parking, since the availability and cost of parking affects accessibility by car. Permanent or daytime parking bans on major arteries, charging fees to park on other streets, regulating paid parking on private lots, regulating the free parking provided by institutions and companies to the public or their employees, economic incentives to discourage driving to work, intermediary parking linked to public transit—all are potentially useful measures if applied in the appropriate context to an appropriate degree. Some can also generate revenues for the municipality. In any case, care should be taken when imposing highly restrictive requirements that drive away businesses and residents, or else certain areas of the city might experience depression. Thus, there should be a comprehensive parking policy that is consistent with urban development and sustainability.

Staggering the starting time of various activities can ease congestion somewhat by prolonging the morning rush hour. Restrictions on vehicle use can take a significant proportion of vehicles out of circulation. If such measures are applied only in places and times of heavy congestion, such as downtown areas during the morning and afternoon rush hours, they can have more lasting effects than more widespread restrictions, since there is less incentive to purchase additional cars. Another type of limitation is requiring the purchase of permits for circulation, which vary in price according to how many days a week a car can be driven. Restrictions can also call attention to the congestion problem and encourage people to participate collectively in reducing it.

Road pricing, advocated by many academics and urban transit officials because it is an attractive idea for defraying the costs that society incurs, meets with more resistance by drivers than any other measure. It does seem to achieve results, at least in the short term, but it has been challenged from every imaginable point of view. It is inconvenient for travellers to have to pay to travel in congestion; there are doubts about the forms in which it is applied; it is criticized for the impact it has on areas adjacent to those subject to pricing;



it is deemed inequitable for low-income travellers; there are fears about the degradation of activities in areas subject to pricing; the long-term effects on urban planning are called into question, since road pricing promotes urban sprawl unless strict land use controls are imposed; and not least, there are allegations of inconsistency with theory if this measure is applied without other related prices, such as those of green areas, being subject to marginal cost pricing. Even some original supporters of road pricing have changed their minds and are now sceptical. It appears to have limited possibilities for application, unless there is some city other than Singapore (which has very special conditions) manages to implement it successfully. Maybe its time will come in developed countries first, if congestion reaches intolerable levels, if other effective measures do not appear on the horizon, and if the theoretical and practical doubts that still remain can be resolved favourably.

And finally, driver education as an ongoing effort beginning in early childhood can contribute to reduced congestion by teaching drivers to be disciplined and respectful to others, be they pedestrians or other drivers. Pedestrians, in turn, should also be taught to follow the rules of the road and cross streets only at the appropriate times and places.

Demand-side measures should be analysed carefully to mitigate any undesired negative effects. In particular, care should be taken to avoid the depression of certain areas of the city and damage to urban sustainability.

Resistance to demand-side measures may subside as travellers begin to view them as useful tools for combating congestion. They may gain more acceptance in developed countries, since there is more awareness of tradition, historic preservation and the environment in those countries.

#### **4. Why take action against congestion?**

Combating congestion carries with it costs of varying magnitude. Some must be paid by public agencies that implement the measures; others are paid by the citizenry as a whole, and in particular, those related to demand-side actions are paid by motorists.

There is no doubt that the brunt of congestion is borne by its primary creators, car drivers. Especially if public resources must be invested, the question must be asked, to what extent should drivers be saved from something that each of them as an individual has brought about as a result of a conscious decision based on strong personal preference? If motorists were the only ones harmed by congestion, one might conclude that they should be abandoned to their own fate, until the majority of them showed a clear willingness to cooperate actively in alleviating the situation and accepted measures that might inconvenience them in some way.

Some effects of congestion have a wider impact, however, and it is necessary to lessen the impact to protect people who do not contribute to it, and to save the city from worse problems. The consequences of congestion

include, but are not limited to, slower circulation of buses, higher bus fares, more accidents, increased fuel consumption, exacerbated environmental pollution, threats to competitiveness, impaired sustainability of urban life and damage to the quality of life.

The very nature of their jobs requires the authorities to serve the common good. In the context mentioned above, the adoption of measures designed to achieve the following ends is justified:

- Strengthening the roadway system as a public asset and restoring any loss of public service provided by the system, facilitating the free circulation of those who contribute little or nothing to congestion. This consists primarily of guaranteeing efficient routes for public transit, providing certain preferences in circulation and, where appropriate, establishing segregated lanes so that mass transit vehicles are not impeded by congestion;
- Ensuring that pedestrians have adequate space;
- Keeping contaminant emissions under control; and
- Limiting congestion so that it does not threaten the quality of life and the sustainability of cities.

Reducing congestion also results in lower emissions of atmospheric contaminants, since the transport system in most cities of the world is one of the main contributors to air pollution. Therefore, a comprehensive strategy for attacking these two problems can lead to more efficient solutions than the application of isolated measures that deal with each one separately.

## **5. What next?**

Traffic congestion in large cities is worsening so fast that the authorities urgently need to devise an appropriate approach to the adaptation of urban transport systems, including both public transit and cars, at the times and places with the heaviest congestion.

The strong adverse effects of congestion in both the immediate and long terms require multidisciplinary efforts to keep it in check, since there is no possibility of eliminating it altogether. This raises the challenge of designing policies and measures that will help moderate and control congestion. The problem is complex, and the most appropriate solutions will not be found easily. All indications are that a combination of actions should be tried with respect to both transport supply and demand, in terms of rationalizing the use of the public motorways.

In the context of cities in developing regions, although local conditions must always be taken into consideration, the most advisable approach seems to be to undertake the following measures:

- Redesigning intersections
- Improving marking and signposting
- Rationalizing on-street parking
- Staggering schedules
- Coordinating traffic lights
- Introducing reversible-flow lanes on some streets
- Implementing segregated bus lanes, accompanied by a restructuring of public transit routes

It should also be recognized that basing mobility primarily on car driving is not sustainable in the long run, though it is not necessary to think of prohibiting cars. They have many applications that facilitate urban life, such as pursuing social activities, shopping, or travelling to distant locations. Taking advantage of this product of development is not objectionable if the inherent costs are paid. Using the car every day to commute to work or school in areas of heavy traffic, on the other hand, will inevitably generate congestion and pollution, as well as other major detriments to society. Individual transportation has its place, but it should not be exaggerated. Therefore, a better balance between owning and using cars should be attained.

It is worth pointing out that in the short term, measures aimed at tempering the indiscriminate use of cars are politically costly. The authorities, who are elected for terms of a few years, tend not to take a long-range perspective in their decision-making, so sustainability has not often guided transport policy in Latin American cities. This approach is even more difficult in cities that are subdivided into several municipalities that compete among themselves to attract investment and may encourage car driving as part of that effort. A single metropolitan transit authority can be a good way to reverse this situation.

In short, a long-term strategic vision of the city's development must be devised to strike a balance between mobility, growth and competitiveness, all of which are very necessary in today's world, and the city's sustainability and quality of life. This is a complex task, calling for high professional and leadership qualities on the part of urban planning and transport authorities.

Keeping congestion under control is an ongoing, never-ending task. Tools exist for this purpose, some of them more effective and some of them more readily accepted than others, but a set of measures which has the support of the local population can avoid the risk of succumbing in the face of the modern scourge of traffic congestion.



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