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TITLE **Technology options for medium sized cities**

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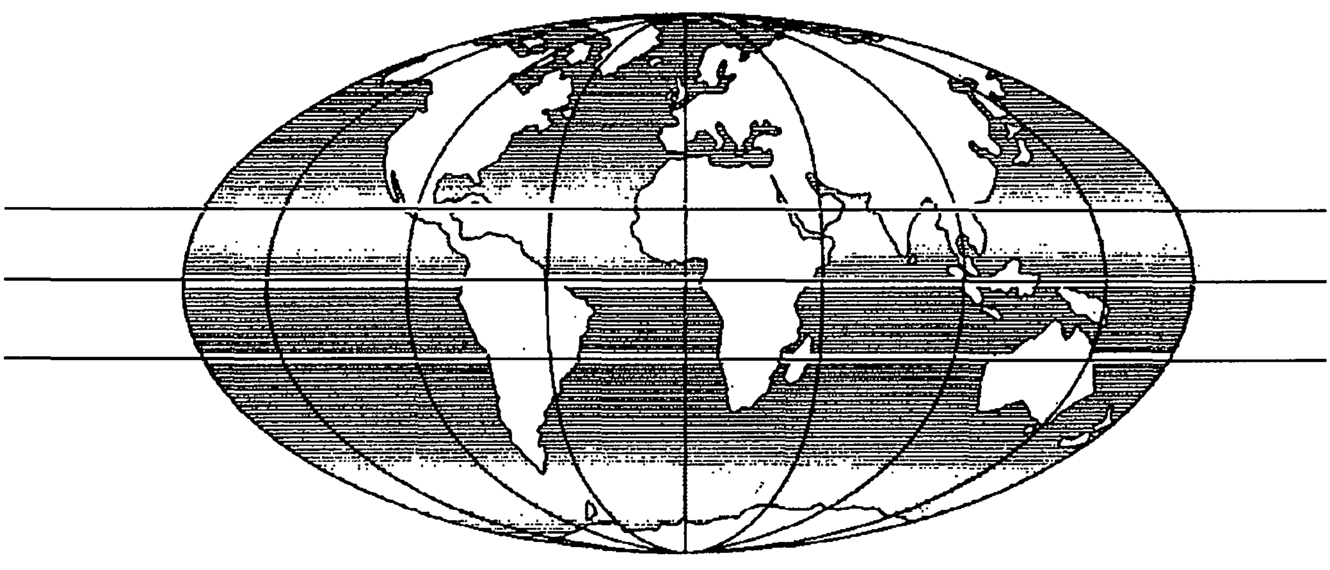

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## INTRODUCTION

The shape and structure of a city can be influenced by its choice of transport facilities. This can be most clearly illustrated by contrasting the urban sprawl of car-dominated Los Angeles with the much denser, public transport oriented cities of Europe. It is therefore important to choose the right transport technology as part of an overall policy.

This paper considers the mass transit technology available for medium sized cities. The term mass transit as used here refers to any urban transport system carrying large volumes of people, usually along well-defined corridors connecting suburbs to the city centre. This paper focuses on those mass transit systems that commonly use a reserved right-of-way for some, or all, of their route length; this includes metro railways (Fouracre et al. 1990), busway transit and Light Rail Transit (LRT) (Gardner et al., 1991,1994).

## MASS TRANSIT SYSTEMS

### The options

For the purposes of this paper, the following definitions have been used to distinguish between the various rail-based mass transit options:

- A metro is often referred to as an underground railway, but can be any grade-separated urban railway. The track and electric vehicles are similar to suburban railways, though with closer station spacing. Trains may have 6-8 cars, with a total capacity of up to 3,000 passengers.
- LRT usually employs vehicles and track construction which are less substantial than a full metro. Some systems, including those of Manila and Istanbul, use exclusive track and high platforms similar to a metro. Other systems have at-grade crossings and low level platforms. LRT trains may be made up of two or three cars, with a total capacity of up to 750 passengers.
- Trams are a basic form of LRT which have limited rights of way, sharing roadspace for much (if not all) of their route length with ordinary traffic. Tram cars are likely to have lower capacity than LRT cars, and are usually operated singly or in pairs.
- Busway transit includes a right-of-way for the exclusive use of buses, with at least one section of busway and some additional features like well-designed bus stops, special operating methods (bus convoys or express operations) and efficient fare collection methods. Clearly defined routes with names like 'green line' or 'circle line' can add to the image of the service.

### Infrastructure Type

The main options for mass transit infrastructure are

- underground tunnels
- elevated
- surface-segregated
- surface-street running

Underground tunnels are mainly used for high-capacity metro systems, though there are some LRT and tram systems which make use of short underground sections. An underground tunnel clearly has the least impact on the city landscape. Disruption to the city during construction is low for bored tunnels, but can be severe if using the 'cut and cover' method.

Elevated viaducts offer many of the same operational benefits as tunnelling, but do not require expensive ventilation and lighting. Maintenance requirements are high, however, and the visual intrusion on the city can be severe. The Manila LRT uses a heavy concrete structure that would be totally unacceptable in cities with more exacting standards of aesthetics.

Tunnels and elevated viaducts are mainly the preserve of metros and LRT, though there is no reason why busway transit could not be given the same facility. In practice, busways tend to be exclusively at surface level, although in Belo Horizonte a busway tunnels through a hillside. In Runcorn, UK the busway is elevated through the central shopping district.

Surface-segregated systems usually have a dedicated road lane (or other travelway) which is in some way physically segregated from the rest of the road. (This can be achieved with studs, fences, bollards, etc.) Junctions with other traffic are at-grade, though it is becoming increasingly common for surface running transit to have priority at road crossings by means of selective detection and traffic signal priority. This is one of the features of the Tuen Mun LRT system in Hong Kong (Bodell & Huddart, 1987). Benefits are less than predicted, however, because tram drivers, unable to steer away from collisions are reluctant to travel through signalised junctions at speed, even with a green light.

Street-running is mainly confined to older, well-established tram systems, and to buses. Very few mass transit systems use what might be thought of as an optimum solution, with street running sections on links, and elevated sections over busy road crossings. The relatively poor ability of rail vehicles to climb gradients might be one reason for this, although some underpasses are used on the Tunis LRT.

**Vehicle Type**

Two main vehicle types are used for mass transit; buses which are usually powered with diesel engines, and rail vehicles, which are normally electric-powered.

Electric vehicles have a major advantage in that the energy used for their propulsion is generated remotely. There are therefore no **local** emissions, though this does not mean (as sometimes inferred) that they have zero pollution. In the Czech republic, for example, electricity for transport is generated using brown coal, which is responsible for some of the worst pollution in Europe.

Buses are usually smaller than LRT vehicles, but they are often considered to create more visual pollution, since the bus usually has a less attractive image. If poorly maintained, buses can also be a source of pollution. This is frequently given as a reason for pursuing a rail-based system (though it is rarely used as a justification for improving existing buses).

**Route alignment and other design considerations.**

The number of people using a transit system will depend upon how well it serves the principal attractors and generators of trips in a city. The best route alignment usually lies along the area where buying land for stations and track is at a premium. Some mass transit schemes have taken the easier option of diverting the route over lower cost land to save money. This has had an adverse impact on passenger carriage and revenue. A major study of metros by Fouracre et al (1990) found that the choice of route is critical. Passengers are very unwilling to walk more than 400-600 metres to a station, especially in regions with hot climates.

The United Kingdom has seen considerable shrinkage in its national railway network during the latter part of the twentieth century. This has resulted in disused railway tracks and route alignments which would appear to be an attractive choice for mass transit use. Examples of this can be seen in both the Tyneside and the Manchester light rail systems; existing railway tracks have been used in the suburbs, with the central area traversed by tunnel in Newcastle, and by street-running in Manchester. One drawback is that the railways which were laid during the last century may serve areas which are no longer large attractors or generators of traffic.

A problem with using existing railways is that often the best aligned routes are still in use for commuter rail. In some cities in Germany, LRT systems co-exist with inter-city electric trains on the same track.

However, because of the different voltages used, this can cause technical problems of implementation and maintenance.

One of the key features of LRT (compared to metros) is the ability to follow tight curves and steep gradients. This means that LRT can be threaded through a compact city centre network. It is also relatively easy to change LRT routes as required to meet changing demand conditions. This flexibility of routing is also a feature of busways, although in this case it can be a disadvantage. Property developers will be reluctant to invest in land benefiting from an adjacent transport facility if they think this can be removed at the whim of future politicians.

Using a selection of bus priority measures, a mass transit system can be tailored to the demands of a city in imaginative ways. For example a bus can meander through a housing estate to collect passengers. The bus can then use a standard motorway until it reaches the beginning of the Central business district (CBD). At this point a single central lane could be segregated for buses only - inbound in the morning, outbound at night. The traffic signals in the CBD can be set to give priority to buses either with special detectors, or by using SCOOT (Split, Cycle and Offset Optimisation Technique). A journey of thirty kilometres from suburb to centre may therefore only require a few kilometres of reserved track.

The accessibility of bus-based systems can therefore be much greater, in that the same vehicle can use residential roads, and then travel within the city centre. Metros and LRT are often planned on the assumption that passengers will use feeder buses to reach stations. In practice, passengers dislike interchanging, and prefer to use the same vehicle for the entire journey. Through-ticketing provides a positive incentive to make an interchange, but is not always easy to implement.

## PERFORMANCE INDICATORS

There are many popular misconceptions about the relative performance and costs of the three main mass transit options. Many promoters (and some transport professionals) have produced graphs, (sometimes with un-labelled axes), showing buses at the bottom, metros at the top, and an LRT system somewhere in the middle. Until now, however, there has been little research evidence to support or refute this hierarchy.

For the purposes of this paper, the options will be compared primarily by cost, capacity and speed. Other factors that will influence choice of mass transit system are also discussed.

### Costs

Cost data vary according to design standards, construction procedures, exchange rate variations, and so on. The overall capital costs for a complete system are estimated in Table 1. The more grade-separation, tunnelling, use of heavy rolling stock and sophisticated control equipment, the higher the cost.

**Table 1. Capital costs of mass transit schemes: costs in US$ millions (1993 prices)**

| | *Bus lane* | *Busway transit* | *Tram* | *LRT* | *Metro* |
|---|---|---|---|---|---|
| *Capital cost per route km.* | *< 0.5* | *2.0-10.0* | *5.0-15.0* | *10.0-30.0* | *40.0-90.0* |

*Note: includes rolling stock, except in case of bus lanes*

There is little doubt that a metro can be as much as a hundred times more expensive to build than a busway. A new scheme involving underground construction could easily exceed one billion US dollars. At such prices city (and even national) economies can be affected.

**Operating costs**

The key components of operating a transit system are labour, energy and replacement of materials. Estimates of operating cost per passenger km are given in Table 2. These costs include depreciation on equipment, but not on the initial infrastructure or any financial charges. Given that capital costs can equal operating costs over the lifetime of a rail project, it is clear that operating cost alone is not a good indicator of the cost a system will incur.

**Table 2. Operating costs of mass transit systems costs in US cents (1993 prices).**

| | *Bus on bus lane* | *Busway transit* | *Tram* | *LRT* | *Metro* |
|---|---|---|---|---|---|
| *Operating cost per passenger km.* | *3-8* | *8-12* | *3-12* | *12-15* | *15-23* |

** excludes depreciation and interest charges (extensive in the case of metro)*

**Financial Performance**

Little is known of the financial performance of low-cost mass transit schemes. In the case of busways, the scheme's performance is usually subsumed within the total financial performance of the participating bus company; neither would it be normal for the capital costs of the track to be included in bus company accounts.

Very few public-sector bus or rail services survive entirely from farebox revenues alone. Table 3 gives some indication of the cost recovery that can be expected from typical systems. Very different results can be achieved from LRT and Metros according to the income of passengers, population density, and depending on the political decision of whether to maximise occupancy or minimise subsidy. Hong Kong has a farebox/operating cost ratio of 2.2, but two-thirds of the metros studied by Fouracre et al. (1990) required an operating subsidy.

**Table 3: Approximate estimated ratio of operating costs recovered from farebox.**

| | *Private Operated Buses* | *Public Sector Buses* | *Tram* | *Metro* |
|---|---|---|---|---|
| *Percentage of costs recovered from farebox* | *100+* | *62* | *40-60* | *20-160* |

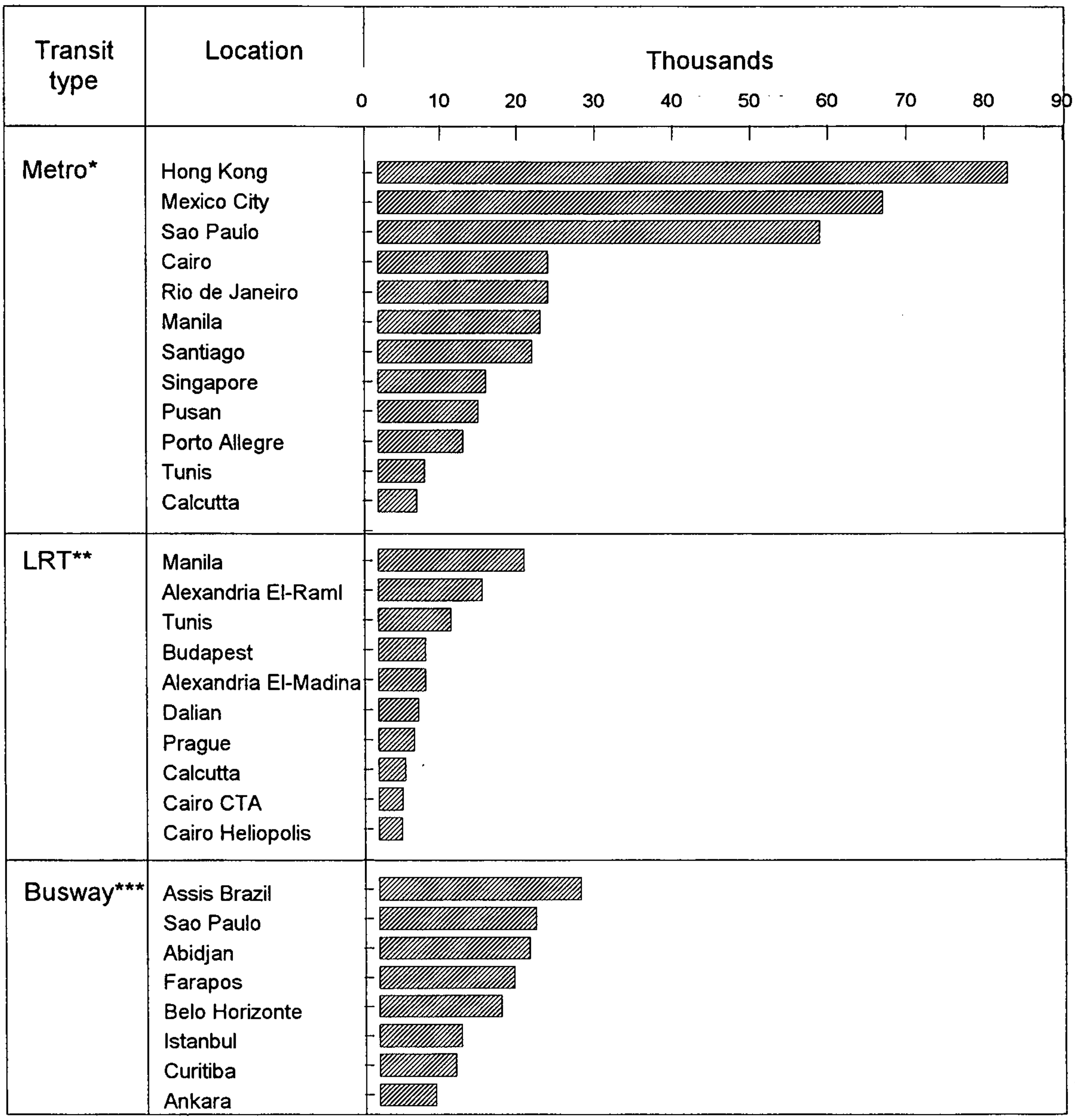
**Capacities**

Although the majority of European Cities are built to a pattern and density such that extremely high corridor passenger flows are not common, the capacity of a scheme at some peak points may be an issue. The TRL research on mass transit performance (Fouracre et al, 1990; Gardner et al, 1991; Gardner et al, 1994) placed a high priority on fieldwork at the site of mass transit systems in order to judge the actual capacities, and the factors which influence it. The results are shown in Figure 1. It is clear that the two largest cities of the World; Mexico City and Sao Paulo; and the densely populated Hong Kong, have conditions producing flows only a metro could carry. For many other cities, however, and for the secondary corridors on the largest cities, alternatives are available.

The TRL findings (Gardner et al, 1994) questioned the generally accepted idea that an LRT system has a higher capacity than busways. In fact the opposite appears to be true. Even in Manila, where the LRT is operating under near-saturated conditions, and where there is full segregation from other traffic, passenger flows are less than on several busways.

Although in theory a train with a passenger carrying capacity of 2000 passing every two minutes produces an hourly capacity of 60,000 pass/hr, in practice this is rarely the case. Each train must wait for the one in front to finish loading, and follow at a safe stopping distance. Short, consistent headways give higher flows, but this requires efficient scheduling and timekeeping. With on-street

**Figure 1: Maximum passenger flows per hour per direction**




**Fouracre, Allport & Thomson (1990)*
***Gardner, Rutter & Kuhn (1994)*
****Gardner, Cornwell & Cracknell (1991)*

running in a busy city there are many opportunities for delay, and these delays can become cumulative. A high degree of segregation, such as in Manila, can help improve capacity, but this will add significantly to the costs.

In contrast, the busway has unrivalled flexibility, and appears perfectly suited to a range of conditions. Delays to a single bus affect only one hundred people, and other buses can overtake if necessary, to provide a continuous high-capacity service.

**Speeds**

An important consideration for an operator is the commercial speed. This is the average speed that can be achieved when allowance is made for passengers boarding and alighting, time at termini and for traffic control measures (Table 4). These influence the service level that can be provided for customers, and vehicle speed also determines the number of vehicles and drivers that will be needed to provide a set level of service.

The commercial speed is also related to the maximum speed of the vehicle, and to braking and acceleration characteristics (Vuchic, 1981). It might thus be expected that electric trains would be significantly faster than buses. In practice, the TRL research has revealed little difference, and using multiple regression analysis to allow for factors such as station spacing, the findings suggest that the inherent difference between busways and LRT is not statistically significant.

**Table 4: Approximate estimated commercial speed for selected systems.**

| | *Bus in CBD mixed traffic* | *Busway transit* | *Tram* | *LRT* | *Metro* |
|---|---|---|---|---|---|
| *Commercial Speed km/h.* | *10* | *18-26* | *12-16* | *19-29* | *29-36* |

**CHOOSING THE SYSTEM TYPE**

Ideally, a system should be chosen to optimise the economic benefits to cost ratio, with some allowance made for unquantifiable and non-user factors e.g pedestrian safety and air quality. In practice, this is rarely the case, for reasons which, although visible, are difficult to rationalise. These can be categorised into three basic elements: historical precedent and/or accident; difficulties in quantifying some of the benefits and non-altruistic decision making.

Much of the underground railway in London was built over one hundred years ago. As a result, it does not always serve the areas which are of current developmental interest, such as Docklands. Significant areas of London, in particular the East end, are poorly served by underground rail links.

In Cairo and in Calcutta, tram systems were introduced during the last century, and must have then provided a fast and comfortable service. Today, the tram is considered outdated and subservient to the modern metros in both cities; they are also treated with disrespect by other road users (and even by city planners.)

If one assumes a system is built only when the authorities decide that potential benefits outweigh costs, this implies that some notional value is given to non-financial factors. These would include environmental and safety aspects, and attempts have been made to allocate costs to these. However, it is still difficult sometimes to understand decisions that have been made, and it appears that other factors are involved. This is the subject of a current research programme at TRL.

There are many pressures on government, not least in developing countries, to choose a particular mass transit option. The benefits of status or image that a modern transit system can bring to a city appear to have a significant part to play in the decision making process. Furthermore, in countries where "commissions" and informal payments add around 10 percent to a project cost, the attractions of a metro costing over one billion US dollars are obvious. The political desire to 'do something' to build a city's image, bolster support or to reward other favours may influence the choice of system. This favours high cost prestige projects such as modern rail systems, even when these may not be the best practical or cost-effective solution.

**CITY FORM**

Modern cities present a range of development characteristics, dynamic growth patterns, transport infrastructure and operations, and social customs which defy all but the broadest generalisations. Although the absolute magnitude of transport's contribution to shaping urban form is unclear, the planning of urban development is widely accepted and practised. Transport, an important component of urban life, must be included in that process.

The essence of a city centre is that it is the most accessible point from both within and without the city. This superior accessibility is important for many activities, and in particular for those central functions that serve a wide area and/or need a wide labour market: head offices, central government offices and legal institutions, financial institutions, media firms, theatres, department stores, etc. and all the supporting organisations (catering, hotels, etc.) that exist to serve these central functions. The fortunes of the city centre are at risk if the public transport system proves inadequate in supporting these central functions.

**FUNDING**

The revenues from, and operating costs of, a rapid transit system may be similar in nature and as such the system may or may not cover its operating costs, but will probably not generate huge surpluses or deficits. Any surplus on revenues is not likely to make a substantial contribution to financing capital costs, the bulk of which will have to come from public funds.

Experience of funding of rail projects in Europe has shown that although some Governments are prepared to heavily subsidise the very high costs involved, most countries are looking to decrease their involvement, and hence attract private capital. This relies on the notion of 'betterment' in which private interests are willing to pay for the benefits which they might gain as a result of the railway having been built. Such sources are unpredictable and closely dependent on the state of the local economy. Urban rail rarely has more than a marginal effect. Appropriation of increases in land and property values is also liable to stifle initiatives to create and enhance these increases.

Funding from taxation sources may be a more reliable source of funding than that generated from the 'betterment' approach. However, flat rate taxes such as the West German Mineralölsteuer (tax on fuel oil) are more suited to capital rather than operational subsidy. Operational subsidies are more effective when linked to wage or price inflation, although linking subsidies to inflation can remove the incentive to reduce costs. Many alternative sources of funding will work out more inefficient than the straightforward use of public funds. It should be realised, therefore, that the use of a novel taxation method may be more politically acceptable, but it is bound to have some real cost to the community.

The new advanced guided transit schemes are still somewhat of a novelty. They have higher capital costs than more traditional systems, but operating costs are reasonable. Governments everywhere appear to be fascinated with the technology, though the more hard-headed business world may well wish to wait to see some concrete proof of the benefits before becoming involved. Contributions from developmental benefits may provide a useful supplement to fare revenues (amounting perhaps to 10 or 20 per cent), but will not be the major source of funds.

## CONCLUSIONS

Although the strength of the effect is unclear, there is some evidence that transport can influence the appearance and the overall form of a city. Mass transit can be used to sustain the vital function of a city as a centre for social and business and economic functions. In developing cities it can greatly enhance the capacity of the transport provision on key corridors.

The extent of the influence is determined by the choice of transit technology. This, in turn, is subject to a number of conflicting interests, mostly unconcerned with technical capability. Currently it would appear that these favour prestigious rail-based solutions over the more basic busway.

The TRL research programme has found little evidence to justify the high demand for rail-based mass transit. Whilst there can be no doubts over its comfort, and the prestige that it can confer on a city, there are serious doubts over its cost and even its performance. Conversely, the busway offers unrivalled performance and value for money. It has unsurpassed flexibility in that it can be built only where necessary, and as funds become available. Operational costs are minimal. Some Brazilian cities, such as Sao Paulo and Curitiba have also shown that it is possible to provide a busway that has a good, modern image. There are likely to be many opportunities for busways to make a valuable contribution to the re-generation of the medium-sized cities of Europe. If necessary, they can be seen as pre-cursers of new rail schemes or extensions to existing ones. Whether they can be used as replacements for existing rail schemes will require examination on a case-by-case basis.

More important than the choice of mass transit system, however, will be the policies towards the private car. The main priority must be to curtail the growth of private transport use (although as Karlicky has said (1991) private vehicle *ownership*, as distinct from *use*, can be encouraged).

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