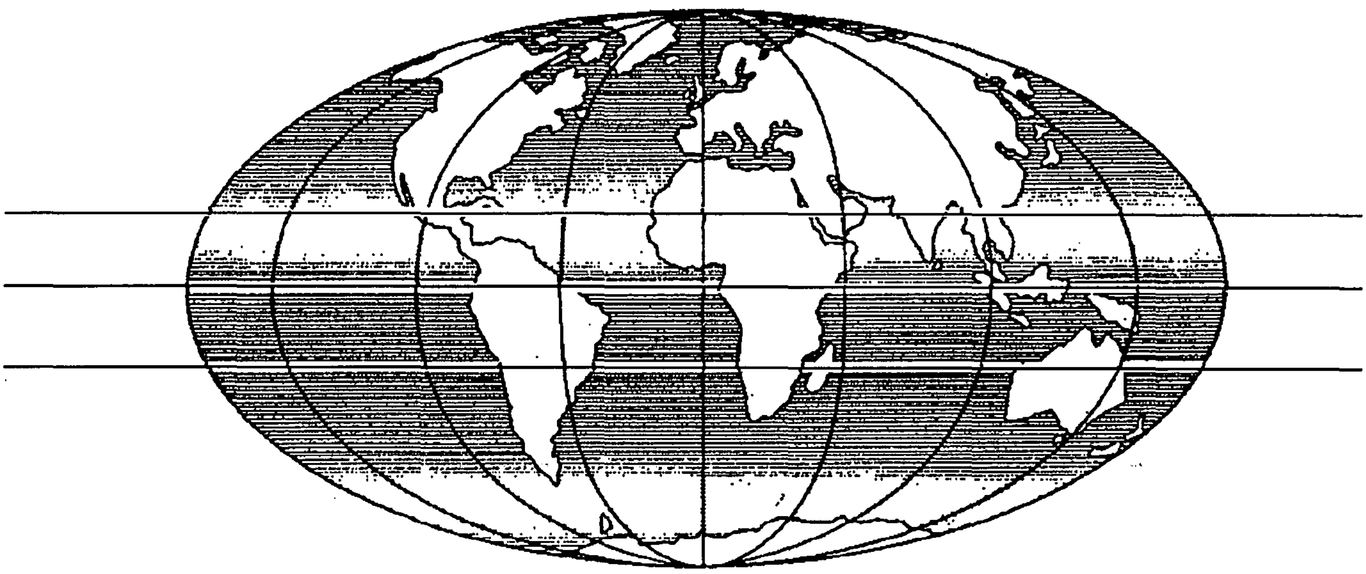
TRANSPORT RESEARCH LABORATORY

ODA

Reprint

TITLE A study of high capacity busways in developing cities

by G Gardner



Overseas Centre
Transport Research Laboratory
Crowthorne Berkshire United Kingdom

Gardner,G (1992). A study of high capacity busways in developing cities. In: <u>Proceedings of Institution of Civil Engineers. Transport. August 1994.</u>

A study of high capacity busways in developing cities

G. Gardner, BSc

Proc. Instn Civ. Engrs Transp., 1992, **95**, Aug., 185–191

Paper 9822

Written discussion closes 15 October 1992

Many of the world's major cities face the ever-increasing problem of traffic congestion. Buses are forced to compete for road space with all other road users and hence frequently fail to deliver an acceptable public transport service.

Numerous cities throughout the world are now planning rail-based metro systems to provide public transport. Because of the extremely high capital costs, however, metros will rarely be appropriate, particularly in developing countries. Modern bus systems, including busways, could provide a viable mass transit option.

This Paper presents the main findings of a TRRL (now TRL) research project on the performance of busways in developing cities. From a case study of eight such systems, capacity figures are presented which show that passenger flows of over 20 000 per hour per direction are possible and that even higher flows might be achievable given the right combination of design and operational features.

A busway transit network, with a dedicated track, traffic signal priority and similar stop-spacing to that of a metro is potentially able to provide a suitable alternative to a rail-based system, at a fraction of the cost. With high-quality buses and a good corporate image, such a system could be attractive to city authorities in many UK and European cities.

Bus stop spacing and design are found to be the critical component of a high-capacity busway transit system, although the provision of overtaking bays, together with efficient ticketing arrangements, can greatly improve throughput.

The advantages of busways for a developing country include their relatively low costs, with minimal foreign-exchange requirement, and much greater flexibility and adaptability when compared to a fixed-route system.

Introduction

Many of the world's major cities face ever-increasing problems of traffic congestion. This can hinder economic growth and cause severe environmental damage. Buses, which are the dominant form of public transport in most developing cities, are locked in this congestion and hence frequently fail to deliver an acceptable service.

2. Many countries have favoured the introduction of heavy rail metro systems. However, a recent Transport and Road Research Laboratory (TRRL now TRL) study of metros in developing countries[1] found that although rail may be the only means of carrying more than 30 000 passengers per hour per direction, a city should exhaust all possible alternatives before opting for a metro, because of the extremely high capital costs.

3. Several cities have implemented innovative and modern bus systems, including busways, as an alternative mass transit option. Such systems have many potential benefits, but relatively little is known about how well they perform.

4. In 1989 TRRL, with Traffic and Transport Consultants Ltd (TTC), initiated a study of busway transit in developing cities.[2] The study objectives were to review the performance of existing bus priority systems, to determine their appropriateness and scope for general application and to establish relationships between passenger demand, design features and operation.

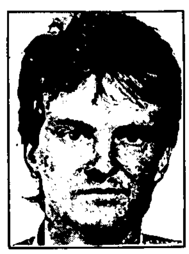
5. The impact of bus priority on general traffic is dependent upon the specific layout of a city's road network and must be examined using standard transport planning techniques. This has been discussed elsewhere (for example by Holman *et al.*)[3] and was not included in the present study.

6. As many popular misconceptions exist over the capacity of buses relative to rail-based systems, a high emphasis was placed upon case study measurement of eight busway schemes (Table 1). To ensure accuracy, all surveys were personally supervised by a member of the study team.

Busway features

7. The concept of a bus-lane is well-known, being an area of road space reserved for buses only by the use of paint and signs. This gives buses priority over other vehicles leading to fewer delays, especially on the approach to junctions. A 'busway' (as shown in Fig. 1) includes some form of physical segregation.

8. A variety of layouts are possible, including 'lateral' busways in the nearside lane, and 'median' busways usually occupying the



G. Gardner, Senior Scientific Officer, Overseas Unit, Transport Research Laboratory

Table 1. Physical characteristics of busways surveyed

City	Location	Length: km	Average stop spacing: m	Average junction spacing: m	Special features
Abidjan*	Blvd de la Republique	1·27	400	160	None
Ankara	Besevler–Dikimevi	3·6	310	410	None
Belo Horizonte	Av. Cristiano Machado	8·57	610	920	Overtaking at stops
Curitiba	Eixo Sul	9·5	430	430	Trunk and feeder
Istanbul	Taksim–Zincirlikuyu	2·27	310	410	None
Porto Alegre	Assis Brasil	4·5	580	410	Bus ordering
Porto Alegre	Farrapos	2·8	560	390	Bus ordering
Sao Paulo	Av. 9 de Julho/S. Amaro	7·9	600	530	Overtaking at stops

* All median systems except Abidjan (lateral) and Istanbul (mixed).

central reserve of a dual-carriageway. A typical busway might extend for 1–10 km, incorporating several stops and junctions. Bus-stops for median busways are in the centre of the road, having pedestrian crossings to ensure safety.

9. In order to achieve high performance and to realize the full potential of a busway, good design, complemented by operational and management measures are necessary. With very high flows, management measures are also needed to ensure that buses at either end of the busway are fed into the normal street network, or into a terminal area with maximum efficiency.

10. General traffic may require diversion, but will usually travel alongside the busway, with crossing movements restricted using 'G' or 'Q' turns. In some cases, special detectors enable buses to be given preferential treatment at traffic signals. With very heavy flows, however, buses can arrive at a rate of one every fifteen seconds, producing a constant 'call' which renders simple vehicle actuation inoperative.

11. Busway transit is the term used to describe busway schemes which include a package of performance-enhancing operational and design features to provide a full mass transit system. A busway transit system might have many of the attributes of a metro, that is: fixed routes which are clearly named (for example, 'central line', 'green line' etc.), dedicated named station/stops and a corporate image for vehicles, timetables and publicity material.

Busway performance

12. On each of the case study busways, synchronized watches and number-plate matching techniques at points 1–5 km apart, were used to measure speeds. Occupancies were measured on a 7-point scale, with judgements, where required, tending towards under-estimation. Key indicators of the performance of the busways are shown in Fig. 2. In addition,

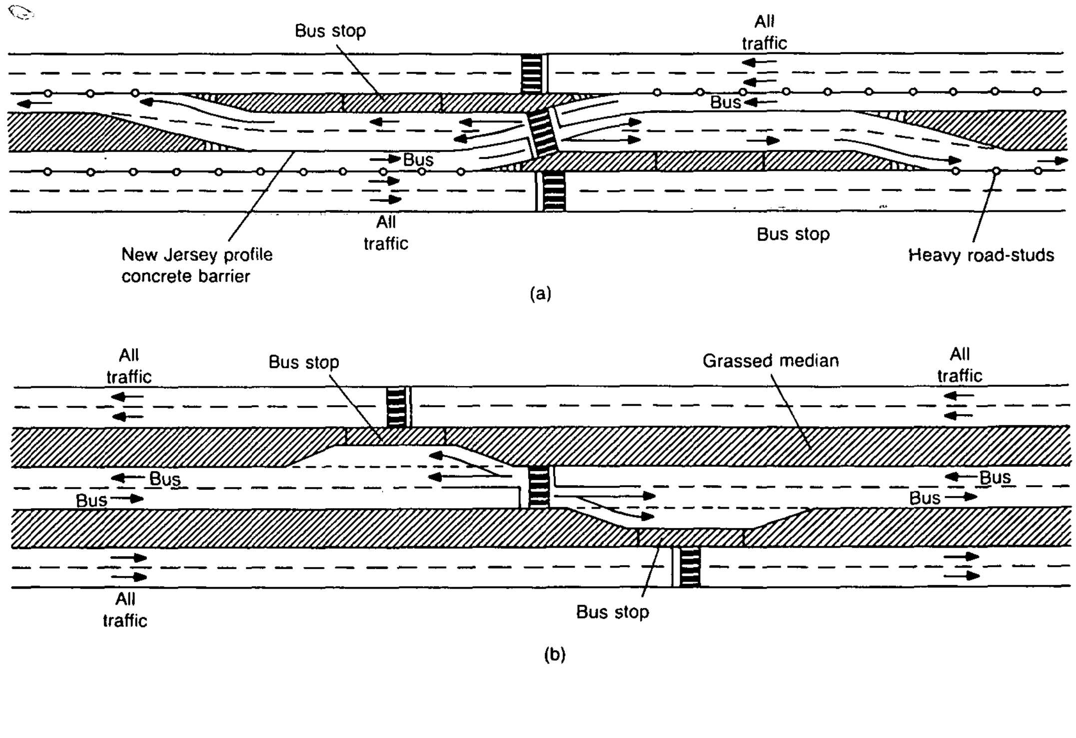


Fig. 1. (a) Typical bus layout, Avenida 9 de Julho, Sao Paulo, Brasil; (b) typical bus-stop layout, Avenida Cristiano Machado, Belo Horizonte, Brasil

several bus-stops were selected for more detailed surveys; these are discussed in the section on performance of bus-stops.

Case study results

13. *Bus flows* Peak hourly bus flows per lane per direction ranged from 91–378 per hour in the morning peak and from 80–304 per hour during the evening peak. Maximum flows exceeded 200 per hour at five of the sites, and exceeded 300 per hour at two sites. This corresponds to a maximum recorded number of available passenger places of 39 400 per hour (during the morning peak, taking nominal bus capacities, not crush loading).

14. *Passenger flows* The maximum recorded line-haul passenger throughput was 26 100 passengers per hour per direction (p/h/d) on Assis Brasil, Porto Alegre (during the morning peak when passengers at the busy city centre bus-stops were predominantly alighting). The highest evening peak passenger throughputs were recorded in San Paulo (20 300 p/h/d) where an overtaking lane at bus stops facilitates high throughputs at acceptable speeds.

15. The highest recorded passenger throughput on a basic busway, (i.e. one without any special operational measures) was 19 500 p/h/d in the predominantly boarding direction in Abidjan, this occurred under conditions of extensive bus queueing and severe crush loading during the evening peak.

16. *Bus speeds* Average bus commercial speeds along the case study busways ranged from 12·0 to 24·6 km/h during the morning peak and from 8·0 to 29·3 km/h during the evening peak (Fig. 2). Bus-stop and intersection spacing, and the provision of special operating features, would appear to be the main influence on bus speeds.

17. In the three city-centre sites, where stops and junctions occur frequently, average speeds were around 11 km/h. On the suburban busways, where longer distances exist between stops and intersections, averages of around 21 kmph were achieved. The suburban busways also tended to have special operating features, and work is currently in progress, using multiple regression techniques, to estimate the relative influence of these factors.

Special operational measures

Study results

18. The study revealed that certain physical and operational characteristics are linked to busway performance. These include the following.

19. *Trunk and feeder services* With trunk-and-feeder services, very short headways are used on the trunk routes on the busway, with other services rerouted to feed terminals at the end of the busway, rather than travelling through to the city centre.

20. As all passengers use the same trunk service, all passengers board the next arriving bus, each bus fills up and very high load factors (that is passengers carried/nominal capacity) can be achieved. The limited number of routes, however, does result in enforced interchange for many passengers using the

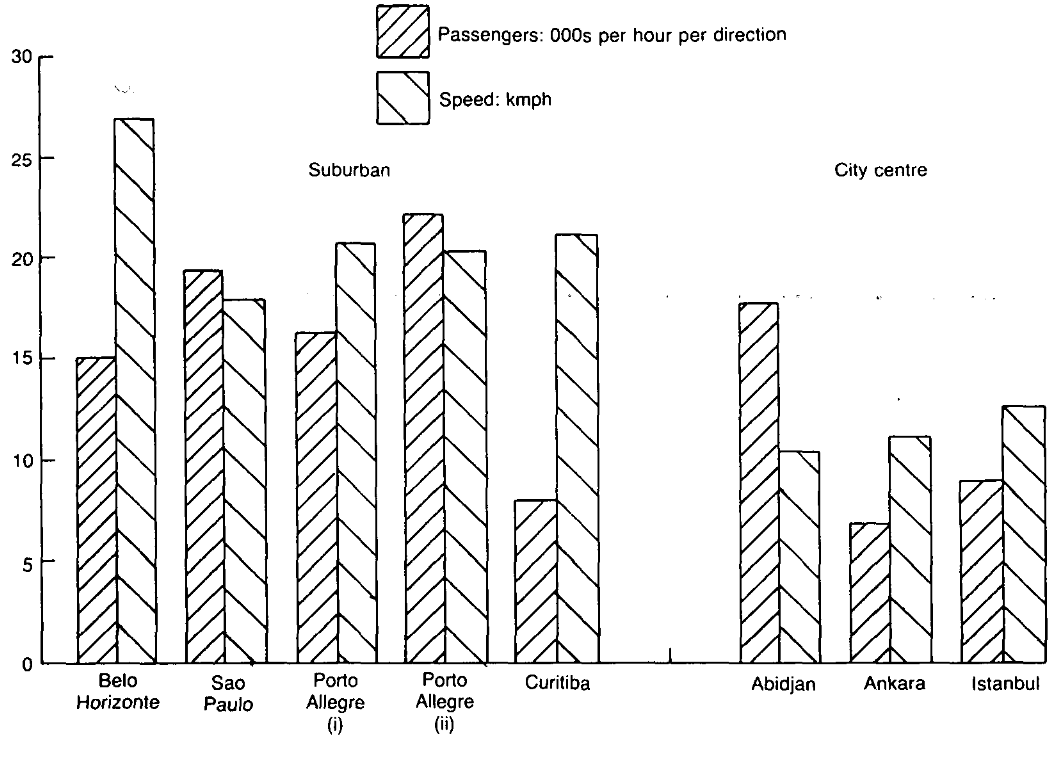


Fig. 2. Summary of busway performance

Fig. 3. Median busway with a very high volume bus-stop, Ankara, Turkey

feeder buses, or a limited choice of destinations.

21. In Curitiba, these terminals are enclosed, such that tickets are purchased at the entry to the terminal, rather than on the bus. This reduces boarding times and provides free transfer for those interchanging inside the closed area.

22. *COMMONOR* or *bus ordering* COMMONOR is a technique which involves assembling buses at the start of the busway into a sequence corresponding to the route and stand order at individual bus stops along the busway.[4] Buses then proceed along the busway in a manner similar to a train; boarding of buses at all stands takes place concurrently, thus co-ordinating the time lost through deceleration etc. and reducing the queueing time associated with loading buses at the first stand holding up all others.

23. COMMONOR was not in full operation during the present study, but the less formal bus ordering system which existed in Porto Alegre, whereby buses are assembled in a regular order, but not necessarily grouped into complete convoys, was associated with better performance than might otherwise have been expected.

Table 2. Average bus travel times (in seconds) by bus-stop category

Activity	No. of passengers at stop	Travel time through stop: s	
		Standard	Overtaking
Boarding	Very high	203	66
	High	154	37
	Moderate	66	37
Alighting	Very high	108	44
	High	57	47
	Moderate	52	n/a

Performance of bus stops

24. Figure 3 shows a very busy bus stop in Ankara which handles more than 4000 passengers in the peak hour (this is more than many stations on the London Underground). As buses usually have only one or two doors available to boarding passengers, passenger movements at stops have a large influence on line-haul performance. As the numbers of boarding/ alighting passengers increase, so bus dwell times at stops increase, and this causes capacity limitation.

Study results

25. *Bus stop surveys* A number of key bus stops were selected for detailed investigation. These were mostly in the case-study busways, but additional surveys took place at stops which had particularly interesting features, such as in Singapore (Fig. 4) and Hong Kong. The times of arrival at the approach and of exit from the stop were noted, the times that the doors opened and closed were taken, and the number of passengers boarding and alighting were counted on a sample basis.

26. *Passenger flows and travel times* Three categories of bus stops were identified in the

study, according to the number of passengers handled

(*a*) 'very high volume' stops, typically at city centre locations, with either boardings or alightings greater than or equal to 2500 per hour
(*b*) 'high volume' stops, typically in local centres, with maximum boardings or alightings less than 2500 but greater than or equal to 1000 per hour
(*c*) 'moderate volume' stops, with both boardings and alightings less than 1000 per hour.

(These all represent extremely high volumes when compared to most European or American bus-stops.)

27. Travel time was defined as from the moment the bus arrived at the queueing area, until it cleared the last bus stand. Large variations were found at each site: mean travel times varied from 26–203 s and loading/unloading (i.e. door open to door close) times varied from 11–109 s.

28. As shown in Table 2, although some of the variation in travel time was explained by passenger volumes, the presence of overtaking facilities was also important. Between 15 and 69 per cent of bus time spent in the stop area was not associated with passenger movement, being mainly due to queues of buses on the approach to the stop and to traffic controls.

29. *Overtaking at stops* With very high flows of buses, queues can build up at stops, and all buses will then travel at the speed of the slowest until there is an overtaking opportunity.

30. All bus stops surveyed which had overtaking facilities, had lower overall delay times than those without. The innovatory parallel stands bus stop in Singapore (Fig. 4), for example, had very much lower delays than comparable sites in Turkey.

31. Overtaking also permits the introduction of limited-stop and express services, making overtaking bays at stops one of the most cost-effective measures to improve capacity and commercial bus speeds under normal circumstances. (The problem found in the UK, of buses being denied re-entry to their lane was not found to exist, as can be seen in TRRL's video.)[5]

32. With overtaking facilities, a bus can leave as soon as boarding is comolete, loading of several routes occurs concurrently and, with very short headways, supply can be matched closely to demand. It is possible, therefore, that the capacity of an efficient overtaking bus stop can be higher than other alternatives which are usually thought to be of higher capacity, but which do not normally have overtaking, such as trolley-bus, guided bus and even light rail.

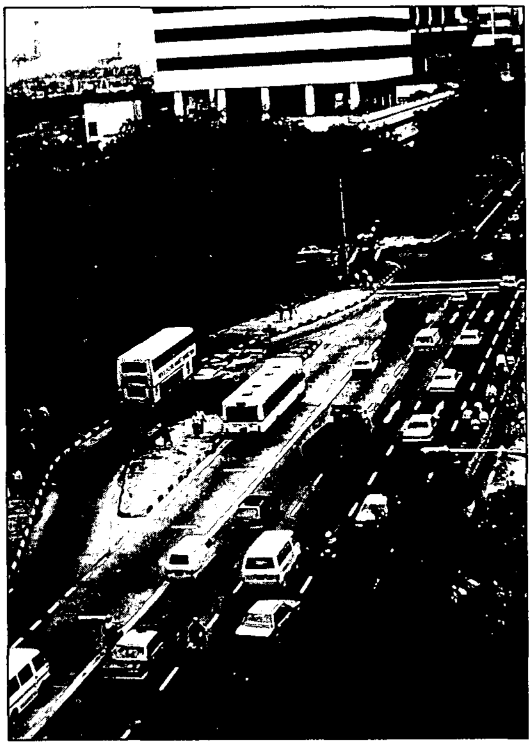


Fig. 4. Innovatory parallel-bay bus-stop, Singapore

Further work will be needed to confirm this, since reliable case study data are not yet available.

33. *Boarding and alighting times* Boarding and alighting times were surveyed at a selection of stops; these varied considerably from one city to another. For example, average boarding times for a typical group of ten passengers ranged from about 19–41 s. As shown in Table 3, boarding times per passenger where free entry onto the bus is permitted were lower, at around 1 s, than those where fare collection restricted entry at about 2 s per passenger.

34. Lost time per bus (i.e. time when doors were open but no passengers were moving) appeared to be fairly constant at around 10 s, although this was greater at the very long bus stops (some were up to 70 m long), and at the very busy bus stops such as in Ankara (Fig. 3).

35. Alighting times measured were in the range 0·4 to 0.9 s per passenger, confirming the well-known fact that boarding times per passenger tend to be longer than alighting times, typically about double.

Busway advantages and disadvantages

36. This study has shown that busways are capable of carrying high passenger flows at acceptable speeds. As shown in Fig. 5, the capacity of the busways studied compares very favourably with many of the metros studied by Fouracre[1] particularly when capital costs are taken into consideration. In addition, the

Table 3. Passenger boarding times by city and fare collection arrangements

City	Lost time: s*	Time/ passenger s	Entry arrangements†	Fare collection method
Abidjan	10·3	0·9	Free entry	Turnstile
Bangkok	9·8	1·2	Free entry	Conductor
Belo Horizonte	5·2	1·5	Free entry	Turnstile
Sao Paulo	8·6	1·3	Free entry	Turnstile
Ankara	23·0	1·8	Driver supervised	Paybox
Hong Kong	13·1	1·7	Driver supervised	Pay driver
Istanbul	9·3	2·3	Driver supervised	Paybox
Singapore	8·4	2·2	Driver supervised	Pay driver

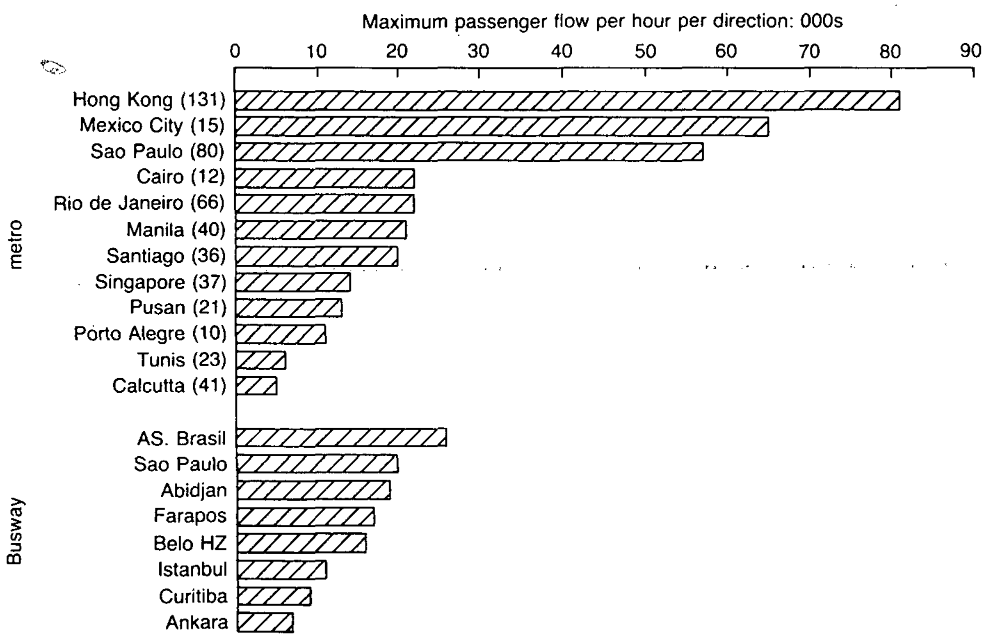
* Lost time represents average delay to all buses, irrespective of number of passengers boarding.
† Driver supervised entry requires single-file boarding, otherwise full width of door available for passenger entry with fare collection on-board.

advantages of busways for the city authorities are

- Self-enforcement: Because a busway physically segregates buses from general traffic, the priority for buses does not need to be enforced by a strong police presence.
- Flexibility and diversity: Since buses can join and leave a busway anywhere, routes from all over the city can use the busway for all or part of their journey. Passengers from a wide catchment area can therefore benefit from a faster service without having to transfer to a faster vehicle, as would be required with a fixed-track system.
- Affordability: An at-grade busway along an existing right-of-way is likely to cost US $400 000–1 000 000 per km (end-1989 values), depending upon the need for utility relocation and other local factors.
  Since busways can be provided with locally available labour, materials and vehicles, the foreign exchange requirement for 'hard' currency is minimized.
- Scope for Incremental Development: Sections of even a few hundred metres of Busway can be useful (whereas rail transit needs a depot and a significant route length before it can attract passengers). Busway Transit can also be enhanced step-by-step (e.g. by adding grade separation at critical intersections; introducing off-bus ticketing etc.) as and when finance permits.
- Existing Experience: busways enhance the use of buses, the predominant public transport mode in most cities, and can draw upon the wealth of experience and knowledge of bus operation which already exists.[6]

37. One of the main disadvantages of busways are that being a mixture of highways, traffic and public transport, their implementa-

ig. 5. Capacity of etro and busway ystems with capital osts



Figures in brackets show capital cost per kilometre of metros (millions US$, 1986), from Fouracre.
Comparable busway costs in region of 1 million US$ plus the cost of buses and terminals.

tion requires co-operation from a number of separate institutions which is not always easy to achieve.

38. Busways can also be criticized for taking road space away from cars. For schemes with low passenger demand, as in the UK, careful transport planning evaluation would be necessary, on a case-by-case basis, to ensure optimum benefits. However, this study concentrated on corridors with extremely high passenger flows of up to 26 000 persons per hour per direction. Under these conditions, since a busway can carry between five and ten times more passengers than a general traffic lane, there would seem to be an overwhelming case, on technical grounds, for providing space for buses at the possible expense of other traffic.

39. Similarly, for such high passenger flows, a bus with a well-maintained diesel engine is clearly superior in environmental terms, than the equivalent number in private cars. A comparison between mass transit options, which will investigate the total environmental advantages and disbenefits of electric and diesel alternatives, is to form the follow-up to the present study.

40. Perhaps the main disadvantage of busways is that they are perceived as being an 'outdated' and 'unclean' technology. Irrespective of the potential demonstrated in this study, the worldwide demand for rail-based mass transit systems continues unabated, with (except perhaps in those UK cities which 'failed' to gain a light rail transit system) little sign of an active lobby for the busway option.

Conclusions

41. The TRRL study has shown that given the right combination of operating features, it is possible for segregated busways to provide a high-capacity mass transit system.

42. For maximum throughput, care should be taken with all aspects of the design, but in particular with the layout of the bus-stops which should, ideally, include overtaking facilities.

43. Operational measures such as bus ordering or trunk-and-feeder services can further enhance performance.

44. As demonstrated in Fig. 5, the passenger carrying performances of busways compares very favourably with that of metros, and at substantially lower cost.

45. Against all of the arguments in favour of busways, the popularity of metros has shown that it is not necessarily technical performance alone that determines the choice of public transport system, and the 'image' of the service can be critical.

Acknowledgements

46. The Busways study team consisted of Dr Philip Cornwell and John Cracknell of Traffic and Transport Consultants, and Geoff Gardner and Phil Fouracre from TRL.

47. This work forms part of the programme of the Urban Transport and Traffic Management Section of the Overseas Unit (Unit head: J. S. Yerrell) of the Transport Research Laboratory, and is published by permission of the Director.

References

1. Fouracre P. R., Allport R. J. and Thomson J. M. *The performance and impact of rail mass transit in developing countries.* TRRL Report 278, 1990.
2. Gardner G., Cornwell P. R. and Cracknell J. *The performance of busway transit in developing cities.* TRRL Research Report No. 329. Crowthorne, 1991.
3. Holman S., Sang A. and Willumsen L. G. Computer assisted design of bus priority schemes. PTRC 19th Summer Annual Meeting, 1991.
4. Szasz P. A., de Carvalho Montans L. and Godoy A. R. *COMONOR: COMbois de ONibus ORdenados naes avenidas Rangel Pestana e Celso Garcia,* Boletim Tecnico da CET no 22, Companhia de Engenharia de Trafego, Sao Paulo.
5. TRRL *Busways.* Video produced by TTC and Herts Media for TRRL, (amateur format), TRRL, Crowthorne, 1990.
6. Cornwell P. R. and Cracknell J. A. The Case for Busway Transit. PTRC 18th Summer Annual Meeting, 1990.