Benefits of Urban Public Transport Subsidies in Australia

Occasional Paper

This Paper was commissioned by the Bureau of Transport Economics to expand the Bureau's understanding of the nature and extent of subsidies in Australian transportation. The Paper looks at public transport in Australian cities and some of the methodologies which can be used in the evaluation of benefits and costs arising from changes in fare structures or from changes in service levels. The methodologies and data used were based on publicly available sources with minimum use being made of confidential data or analysis. However, the assumptions underlying this study reflect the author's views and are not necessarily those of the Bureau of Transport Economics.

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Benefits of Urban Public Transport Subsidies in Australia

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FOREWORD

This is the first Occasional Paper produced for the Bureau of Transport Economics under its current Research Fellowships Scheme. The Fellowships are offered to qualified and experienced people in the public or private sector or in academic institutions who are interested in undertaking a period of research on a specific issue or issues falling within the Bureau of Transport Economics' general charter.

Mr J.S. Dodgson, Department of Economic and Business Studies, University of Liverpool, undertook the study presented in this Paper during 1984.

The methodology, results and discussions are the views of the author and do not necessarily reflect the position or views of the Bureau of Transport Economics.

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May 1985

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The usual disclaimer applies. I alone am responsible for the contents of the Paper, and none of the above individuals or organisations necessarily agree with any of the material or conclusions contained within it.

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This Paper was commissioned by the Bureau of Transport Economics to expand the Bureau's understanding of the nature and extent of subsidies in Australian transportation. The Paper looks at public transport in Australian cities and some of the methodologies which can be used in the evaluation of benefits and costs arising from changes in fare structures or from changes in service levels.

The methodologies and data used were based on publicly available sources with minimum use being made of confidential data or analysis. However, the assumptions underlying this study reflect the author's views and are not necessarily those of the Bureau of Transport Economics.

SCOPE OF THE STUDY

The study was restricted to analysing public transport in seven of the eight largest cities in Australia, namely Sydney (in this study, including Newcastle), Melbourne, Brisbane, Adelaide, Perth, Canberra and Hobart. There was no freely available information on public transport for the seventh largest city (Wollongong). In this city all bus services are privately operated and the rail service in the city is included in the New South Wales State Rail Authority's (SRA's) Sydney region inter-urban network.

This study examines the benefits which accrue from changes in the fare levels, or from changes in the service levels, of the respective public transport services, together with the benefits from the resulting changes in road congestion. The results were then compared with those obtained from the use of the methodology developed in the United Kingdom by Glaister in co-operation with London Transport and the Central Government Department of Transport.

Chapter 2 describes the current public transport position for each of the Australian cities. Chapter 3 considers the benefits of changes in fares and the costs of operating the respective systems. Chapter 4 considers the benefits of changes in service levels and Chapter 5 the benefits derived from a reduction in highway congestion. Chapter 6 presents results for the Australian cities derived by applying a United Kingdom Department of Transport computer model for evaluating the benefits of urban public transport subsidies.

CHAPTER 2-URBAN PUBLIC TRANSPORT SYSTEMS IN AUSTRALIA

This chapter includes a brief description of the public transport systems in Australia considered in the study. The systems are those which operate in the cities of Sydney, Melbourne, Brisbane, Adelaide, Perth, Hobart and Canberra.

SYDNEY AND NEWCASTLE

Public transport services in Sydney and Newcastle are operated by the Urban Transit Authority (UTA) of New South Wales, the State Rail Authority (SRA) of New South Wales, and by private bus companies.

The UTA operates bus services in Sydney and Newcastle, harbour ferry services in Sydney, and a ferry service in Newcastle. In addition, under the *Transport Authorities Act 1980*, it is also responsible for the 'co-ordination and promotion of an efficient urban passenger transport system in the Sydney, Newcastle and Wollongong metropolitan areas'. To this end the UTA liaises with the SRA and with private bus operators, but it does not have direct control over their services or fares, nor responsibility for their deficits.

In Sydney in 1982-83 a fleet of 1527 UTA buses ran 57.9 million vehicle kilometres over 860 kilometres of unduplicated route. The services carried 172.5 million passengers. In addition, the Sydney ferry services carried a further 15.9 million passengers in a fleet of 15 ships and 5 hydrofoils.

The UTA bus fare structure is based on distance travelled, with five fare scales for single journey tickets. Children and pensioners are carried at half-fare. Special tickets are also available for travel by bus and ferry, and for travel by bus and by the Eastern Suburbs Railway. Multi-journey tickets, known as Travelpasses, are sold for weekly, quarterly or yearly periods and permit unlimited travel in specified zones. Some tickets permit travel by UTA bus and ferry, and others permit travel by rail services as well as by UTA bus and ferry services. The weekly tickets are available for purchase by students at half-price. Multi-journey day tickets are also sold, with a half-fare for concessionary purchasers. The UTA is reimbursed by the State Government for the cost of conveying primary and secondary children free to and from school, and for the cost of concessions to children, pensioners and others.

There is an extensive network of private bus services in Sydney. Services are licensed by the New South Wales Commissioner for Motor Transport but, apart from reimbursement for school children and for pensioner concessions, no subsidies are provided. In 1981, 100 operators providing 199 services, with a fleet of 1572 buses, were licensed in the Sydney metropolitan area. The UTA is involved in the planning, development, and scheduling of private bus services.

In Newcastle in 1982-83 the UTA operated a fleet of 192 buses on a 249 unduplicated kilometre route network. The fleet operated 8.0 million kilometres and 15.9 million passengers were carried. Following withdrawal of a private operator, the ferry service between Newcastle and Stockton has been funded since 1983 using chartered vessels.

Rail services in the Sydney and Newcastle areas are provided by the SRA. A major extension to the system occurred with the opening of the Eastern Suburbs underground line in 1979. Most of the suburban and inter-urban network is electrified. Extension of electrification to Newcastle was completed in 1984 and an extension to Wollongong is currently being undertaken. The suburban and inter-urban networks carried 203 million passengers in 1982-83. Some 180 million passengers a year were carried in the late 1970s. This rose to 205 million in 1979-80 and 215 million in 1981-82.

The rail fare structure is based on single journey tickets with fares related to distance travelled, and return tickets available at twice the single rate. Children and pensioner fares are approximately half the adult rate. An off-peak pricing system operates for distances over about 14 kilometres, for which 'Minifare' returns are available for travel after 9 a.m. on weekdays and at any time at weekends. These provide a discount below the normal return fare.

In addition to the multi-modal Travelpasses discussed previously, weekly, quarterly and annual tickets are available for travel between pairs of rail stations. As on the buses, school children are conveyed free to and from school. The SRA is reimbursed for the cost of providing this service, and for the cost of child, pensioner and other fare concessions.

MELBOURNE

Public transport services in Melbourne are provided by government trams and buses, private buses and government trains. Transport services in Victoria were re-organised in 1983, when the new Metropolitan Transit Authority (MTA) became responsible for all public transport services in Melbourne[1]. The MTA took over the government tram and bus services formerly run by the Melbourne and Metropolitan Tramways Board (MMTB). It also became responsible for subsidies for private bus operators in the area, and for the rail services run, formerly by the Victorian Railways (now known as V/Line), in the Melbourne area.

Tram services serve the inner and middle metropolitan areas. There is a network of 221 kilometres of unduplicated route, mostly on street track but with some reserved track routes, and a fleet of some 650 tram cars. There are two main types of car in operation, the W cars built between 1923 and 1956, and the newer Z cars, built since 1975. A new type, known as the A cars, are currently being constructed, while experiments are being conducted with articulated cars. One tram route is being extended. In 1982-83 the system carried 109 million passengers and operated 24.2 million tram-kilometres.

Government bus services operate on routes not served by trams. Where trams and buses run along the same road there are usually restrictions preventing buses setting down or picking up passengers who could make their trip by tram. There are some 280 buses in the fleet, serving a network of 302 kilometres of unduplicated route. In 1982-83 the government buses carried 25.7 million passengers and operated 13.3 million vehicle-kilometres. In total therefore the MMTB carried 134.7 million passengers, 81 per cent by tram, in the last year of its separate existence. These services are now operated by the MTA's Tram and Bus Division.

About 58 private bus companies also provide bus services in Melbourne under contracts with the MTA. Under these contracts the MTA receives revenue from the services and compensates the operators for costs incurred. In 1982-83 subsidies to private bus operators totalled $27.2 million. The private operators carried 54.8 million passengers in 1982-83 and operated some 36-37 million vehicle-kilometres. The private vehicle fleet totals about 900 buses. It is intended that

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1. Ministry of Transport Victoria (1983) contains an outline of the administrative re-organisation and background information on Melbourne's transport system.

integration of the private vehicle fleet will extend to a common livery with the MTA's own vehicles.

Suburban rail services are operated by V/Line's Metropolitan Rail Transport Division but financed by the MTA. In 1982-83 there was a radial network of 310 kilometres of electrified route. Much of this system was electrified in the period between the two World Wars. An underground loop system around the city centre was opened in stages from 1981 onwards. The electrified network has recently been extended to Werribee. In 1982-83 the system carried 80.2 million passengers and operated 14.5 million train-kilometres.

There was a fairly steady increase in journeys made on government tram and bus services in Melbourne from 1977-78 to 1982-83, with an 8 per cent increase on the trams and a 33 per cent increase on the buses. Traffic on private bus routes was more or less unchanged, whereas rail journeys showed a continuous decline from year to year. The overall drop of 15 per cent in rail journeys over the period meant that total public transport trips in 1982-83 were almost exactly the same as they had been in 1977-78, though total traffic in the intervening years had been lower.

All public transport services in Melbourne now share a common fare structure, based on multi-modal tickets. The city is divided into ten zones, or 'neighbourhoods'. Neighbourhood tickets permit unlimited travel on any mode within a two-hour period within either one or more zones. Daily and weekly Travelcards provide unlimited travel for a single day or a week respectively within one or more zones. In addition there are a number of other types of ticket, including single trip tickets and central area short journey tickets. Off-peak Travelcards are available for some rail journeys to the city centre made after 9.30 a.m. on weekdays. Children and pensioners are normally carried at half the equivalent adult fare, and this is reimbursed from the State Government's Community Welfare Services Department.

BRISBANE

Bus services in the Brisbane area are operated by the Brisbane City Council and by private operators. Rail services are provided by Queensland Railways (QR).

In 1982-83 the Brisbane City Council operated a fleet of 564 buses over 676 unduplicated kilometres of route. The fleet carried 44.6 million passengers and operated 22.3 million bus-kilometres. As well as conventional bus services, the City also operates a number of express services (known as Cityxpress) which provide faster services from outer suburbs to the city centre.

Fares are based on a concentric three-zone system. Some free transfers between buses on single journey tickets are permitted. As well as single tickets, there are also multi-journey tickets in the form of 'Day Rover' and monthly periodical tickets. Children and pensioners travel at half-fare, and the Transport Department is reimbursed by the Council for the difference between this concession fare and the full-fare. Some buses, known as district buses, operate mainly as school services, but the general public are permitted to travel on them too. There is no peak pricing as such, but in the morning peak period many buses are 'full-fare' buses, on which every traveller has to pay the appropriate full-fare.

The Queensland State Government provides the Council with a subsidy equal to 60 per cent of farebox revenue, which is defined as passenger revenue *excluding* reimbursement for concessionary travel. The remaining deficit is financed by the Council. The Council also subsidises a private cross-river ferry operator.

As well as the Council services, there are also some 20 private bus operators in Brisbane. These operate mainly in outer suburbs but also provide services from these suburbs to the city centre. Financial assistance is provided by the Department of Transport, which is responsible for licensing the services. Under the *Urban Passenger Service Proprietors Assistance Act 1975-78* a subsidy of 30 per cent of farebox revenue may be provided, with a further subsidy up to a maximum of 10 per cent of revenue 'where necessary to enable proprietors to obtain a fair return on funds invested'. Some relatively small subsidies are also provided to compensate for pensioner concessions and to finance interest payments on bus purchases. In 1981-82 private bus operators carried 7.3 million passengers in the Brisbane Statistical Division, as compared to 42.6 million carried by the Council buses. Hence private bus services carried about 15 per cent of total bus passengers in the city.

As part of its State-wide system, Queensland Railways (QR) operate a 197 kilometre radial network of seven suburban routes in Brisbane. Most of this network has been electrified since 1979, and the formerly separate northern and southern sections joined by a new cross-river bridge opened in 1978. When electrification is complete in 1986 one lightly-used line (to Pinkenba) will continue to be operated by diesel traction, though some peak-hour services on other lines will be diesel-hauled in order to reduce the required investment in electric rolling stock. The new electric trains are faster and more comfortable than the diesel trains, and have generated additional traffic. In 1983-84 35.8 million suburban rail journeys were made, compared with 25.9 million in 1978-79, an increase of nearly 40 per cent over a five year period[1].

Fares are based on distance travelled, with return journey tickets available at twice the price of a single ticket. In addition weekly, monthly, quarterly, and annual tickets are also available. Children travelling to and from school are conveyed free by rail, and QR is reimbursed by the Education Department for the cost of carrying these scholars. Other children, and pensioners, may travel at half-fare. There is no system of peak-hour pricing.

There is no organisation responsible for the overall co-ordination of public transport services in Brisbane. The State Metropolitan Transit Authority was created in 1976 with powers to take over the separate systems, but has not done so. Attempts to implement an integrated fares policy have also not been successful, although some co-ordinated rail/bus tickets are available on certain routes.

ADELAIDE

With the exception of some minor private bus routes, all public transport services in Adelaide are provided by the State Transport Authority (STA). This operates a fleet of 767 buses over a 965 kilometre network of unduplicated routes. The bus system operated 38.5 million bus-kilometres in 1982-83 and carried 51.9 million passengers. These passenger figures relate to journeys rather than boardings; on average each bus journey required 1.3 boardings. (With minor exceptions other operators count the number of journeys as equal to the number of boardings.) A further 2.7 million passengers were carried on an 11 kilometre reserved track tram line operated by the Authority between the city centre and Glenelg. A guided busway to the north east of the city is under construction.

The STA also operates the suburban rail network in Adelaide. The

1. The absolute figures of journeys, but not necessarily the percentage increase, are likely to be over-stated since journeys made on periodical tickets are over-estimated; for example travellers purchasing weekly tickets are assumed by QR to make 14 journeys on their tickets.

passenger network consists of 152 kilometres of route, mostly owned by the STA, and operated with diesel traction. (Australian National Railways freight and a few long-distance passenger trains also operate over some of this network). In 1982-83 12.9 million passengers were carried on the suburban passenger trains.

An integrated fares structure operates for the whole of the public transport network. Single adult fares are based on three zones, with lower off-peak fares for all zone journeys. Children, students and pensioners pay a flat fare equal to less than half the minimum adult fare, however long their journey, but in addition pensioners may travel free between 9 a.m. and 3 p.m. on weekdays. The STA is compensated by the State for carrying passengers at concessionary rates.

PERTH

Public transport services in Perth are the responsibility of the Metropolitan Passenger Transport Trust (MPTT). The Trust operates bus and ferry services, and contracts with Westrail for the operation of train services over a three-route suburban network[1].

In 1982-83 the Trust operated a fleet of 904 buses over a network of 1628 unduplicated kilometres. These buses carried 53.8 million passengers and ran 42.5 million bus-kilometres. The number of bus journeys in the Perth area has remained more or less stable over the last seven to eight years[2], although bus-kilometres and route network operated have had to be increased as the built-up area of the city has expanded. Ferry services across the Swan River carried 0.3 million passengers in 1982-83.

In 1982-83 two suburban rail routes, from Perth to Armadale and to Midland, were open. On these 44 kilometres of route Westrail operated 1.8 million diesel train-kilometres and carried 6.7 million passengers. Since then the line from Perth to Fremantle (closed in 1979) has been re-opened. The MPTT compensates Westrail for the losses on these services.

The fare structure for all modes is based on a concentric eight-zone system. Free transfers are permitted within two hours of purchase of

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1. See Director-General of Transport Western Australia (1982), for a recent discussion of transport issues in Perth.
2. The 1982-83 passenger total was 2 per cent below the 1977-78 figure.

single journey tickets except on those trips which are very short. Multi-ride tickets, which permit ten journeys to be made within specified zone boundaries, are available for pre-purchase. These tickets are cancelled on the vehicle by a machine which also stamps the time of boarding onto the ticket. Children are normally carried at half the adult fare. A scholar's concession ticket is available for travel to and from school at the minimum child fare. Pensioners and other concessionary travellers may travel at one-third of the adult fare.

In 1983 the State Government agreed to pay the MPTT a 'Social Welfare Payment' for that part of its operations provided for 'social rather than commercial reasons'. In 1982-83 this payment was somewhat arbitrarily set at 25 per cent of MPTT expenditure on bus and ferry services and 40 per cent of its expenditure on rail services. Of the $82.0 million total expenditure in 1982-83, $24.5 million (30 per cent) was met from fares and charter revenue from passengers, $6.2 million (8 per cent) from reimbursements for concessionary travel, $23.0 million (28 per cent) from the Social Welfare Payment, and the remaining $28.3 million (35 per cent) deficit was funded separately by the State Government.

HOBART

The Tasmanian Metropolitan Transport Trust (MTT) operates urban bus services in Hobart, Launceston and Burnie. Separate data are provided for operations in each of these towns. In 1982-83 a fleet of 213 buses operated an unduplicated network of 260 kilometes in Hobart. The buses carried 10.6 million passengers and provided 7.6 million vehicle-kilometres. Traffic had declined annually from 1974-75 to 1981-82 although there was some increase in 1982-83, due mainly to the introduction of an off-peak day tripper concession fare of 50 cents.

The fare structure is based on graduated single fares related to distance travelled. In 1982-83 there were five fare bands for adult travel, but children and pensioners paid a single flat fare equal to three-quarters of the minimum adult fare. In December 1982 a daily multi-ride off-peak ticket was introduced for adult travellers; for the purposes of this ticket Hobart is divided into two zones. Unlike other operators, the MTT is not reimbursed separately for carrying passengers at concessionary fares; instead the State Government provides a single payment to bridge the gap between costs and revenue.

There is one private bus operator on the southern outskirts of the city, and some other private operators provide services to the city but with pick-up and set-down restrictions. Apart from reimbursement of pensioner concessions, there are no subsidies provided for private bus service operations in Tasmania.

Finally, there are no urban rail services; the former Tasmanian Railways suburban services in Hobart were withdrawn in 1974.

CANBERRA

All public transport services in Canberra are provided by the ACT Internal Omnibus Network (ACTION) which is operated by the Department of Territories. By July 1984 there was an unduplicated network of 449 kilometres of route, based on three major interchanges, at Belconnen in the north, Civic in the centre, and Woden in the south. These interchanges are linked by a frequent express service, while other services feed into the interchanges or link the suburbs between them.

In 1982-83 ACTION operated a fleet of 352 buses. Of the total 14.5 million bus-kilometres run, 0.9 million kilometres were special school services for which ACTION was separately reimbursed by the ACT Schools Authority. The urban services available to the general public totalled 11.5 million kilometres, special bus hire for 0.4 million, and empty running for the remaining 1.7 million vehicle-kilometres.

A total of 20.5 million passengers (boardings) was registered in 1982-83. This represented almost a doubling of the 1974-75 figure and occurred because of the expansion both of the city and of the coverage of the bus network. It should be noted, however, that in comparison with other cities the interchange-based system means that these passenger totals are inflated because of the need for many passengers to transfer between buses during the course of a single trip (Commonwealth Grants Commission 1984, p. 230).

The fare system is a flat-fare one with a fixed fare per boarding with half-fare for children and pensioners. Books of tickets for single journeys may be pre-purchased at a discount. Adults can purchase a daily or a monthly Buscard giving unlimited travel, while a wider range of Buscards is available for children and pensioners. Some 70 per cent of boardings are made by passengers who have already purchased their ticket. As well as being reimbursed for the cost of school bus services ACTION also receives reimbursements from the Commonwealth Government for the cost of pensioner concessions.

TOTAL SUBSIDIES

Table 2.1 shows total subsidies for the different systems in 1982-83 and the resulting cost recovery ratios. The subsidies include reimbursements for carrying passengers on concessionary rates. Cost recovery ratios vary from 0.12 and 0.14 for the smaller rail networks in Adelaide and Perth, to between 0.35 and 0.38 for the bus systems in Sydney, Melbourne, Brisbane, Perth and Hobart.

TABLE 2.1-URBAN PUBLIC TRANSPORT SUBSIDIES[a], 1982-83

	Sydney		*Newcastle*	*Melbourne*		*Brisbane*		*Adelaide*		*Perth*		*Hobart*	*Canberra*
	Bus	*Rail*	*Bus*	*Bus/tram*	*Rail*	*Bus*	*Rail*	*Bus/tram*	*Rail*	*Bus*[b]	*Rail*	*Bus*	*Bus*[c]
Operating revenue[d] ($m)	56.6	107.9	4.0	49.4	71	17.4	13	17.1	4.8	21.7	2.7	4.3	5.7
Expenditure ($m)	162.7	314.0[e]	18.8	129.7	209[e]	45.6	60[f]	77.4	37.3	62.7	19.3	12.2	20.5
Required subsidy ($m)	106.1	206.1[e]	14.8	80.3	138[e]	28.2	47	60.3	32.5	41.0	16.6	7.8	14.8
Cost recovery ratio	(0.35)	(0.34)[e]	(0.21)	(0.38)	(0.34)[e]	(0.38)	(0.22)	(0.22)	(0.13)	(0.35)	(0.14)	(0.35)	(0.28)

a. Excludes losses on ferry operations (except in Perth) and subsidies to private bus operators.
b. Includes ferry operations.
c. Excludes special school services.
d. Excludes payments to reimburse operators for concessionary travel, but includes miscellaneous revenue.
e. Excludes allowance for depreciation, interest, and other capital charges.
f. Broad estimate based on estimates for earlier years supplied to the Commonwealth Grants Commission. Includes Queensland Railways debt charges, but excludes charges raised on loans by the Metropolitan Transit Authority for electrification.

Sources: Various Annual Reports of Public Transport Authorities.

CHAPTER 3-BENEFITS OF SUBSIDISING PUBLIC TRANSPORT FARE LEVELS

Increases in public transport subsidies may be used either to finance lower fares or to finance increased service levels. Hence it is desirable to consider the appropriate balance between fare and service levels. This chapter considers the measurement of the direct benefits to public transport users of fare reductions, while the next chapter will consider the measurement of the direct benefits of service level (frequency) increases. Dicussion of the benefits that might arise to road users through reduced road congestion, either as a result of lower public transport fares or as a result of higher service levels, is deferred until Chapter 5.

This chapter first considers the measurement of the benefits of fare reductions to public transport users, and the relationship of these benefits to the own-fare elasticity of demand for public transport services. Evidence on this elasticity for Australian cities is summarised and a number of values adopted in order to estimate the benefits from additional expenditure on subsidies. The first part of the chapter assumes zero marginal costs of carrying the extra passengers attracted by lower fares. In part this is justified by indivisibilities in the industry. Because the unit of sale is the passenger journey whereas the unit of production is the vehicle-kilometre, there is often excess capacity in public transport operations, so that marginal costs per passenger are low in relation to average costs per passenger. However, there may be some cost increases as a result of increased passenger carryings.

The second part of this chapter considers additional costs of delay imposed on existing users. This section considers in turn the marginal physical delay imposed by an additional bus traveller, the valuation of such time losses, the overall delay costs imposed by an extra user on different systems, and the impact of these delay costs on total benefits.

The third section of the chapter considers bus and rail operating and other costs. Data on these costs are relevant when absence of spare capacity means that decisions have to be made as to whether it would be worth installing extra capacity to cater for additional users attracted by lower fares. In addition, data on operators' costs (and on the values of time discussed in the second section of the present chapter) are important inputs into the other models to be discussed in Chapters 4 and 5.

DIRECT BENEFITS OF FARE REDUCTIONS AND THEIR MEASUREMENT

The benefits of a fare reduction

Consider a public transport service which operates at a fare of f_0 per trip and for which the demand is T_0 trips per unit of time (see Figure 3.1). Given that the demand for urban public transport services is inelastic, a reduction in fares will require an increase in the subsidy provided for the operator. If the fare per trip is reduced from f_0 to f_1, the demand will increase from T_0 to T_1. Assuming that costs are unchanged, the increase in subsidy will be equal to the loss of revenue from existing passengers (area f_1 f_0 ba), minus the gain in revenue from new passengers (area T_0ac T_1). There will be benefits to public transport users in the form of a cost saving to existing passengers (area $f_1f_0$ba) plus a gain to new passengers (area abc). The area $f_1f_0$ba therefore represents a transfer from the operator to the existing passengers, and hence the benefits of the increased subsidy area are equal to the area T_0bc T_1. These are the consumer surplus benefits of the new trips, a large proportion of which are received by the operator in fare revenue.

Of course, if there were constant returns to scale in the provision of *passenger trips* then benefits would be outweighed by the increase in operating costs since, as indicated at the end of Chapter 2, cost recovery rates are well below 100 per cent for Australian urban public transport systems. However, as noted above, a major feature of public transport services is that, once services are provided, additional passengers can be carried up to the capacity levels of the buses or trains operated at low or zero marginal costs. Most public transport services do operate with spare capacity. This is certainly true of bus and tram services except in the most crowded parts of the peak hours (and perhaps for the very occasional individual service outside the peak) and is probably true of rail services at nearly all times because of the high crush capacities of suburban rail coaches[1]. Hence in most circumstances lower fares will lead to an increase in

1. For example, it has been noted of Melbourne public transport services that 'it is apparent that in the majority of cases, supply exceeds demand for all but a small proportion of peak periods' (Ove Arup Transportation Planning 1981 p. 63).

passengers but to a zero or very much less than proportional increase in operating costs.

Measurement of the benefits of a planned fare reduction shown in Figure 3.1 should be straightforward. Information would be available on the existing fare (f_0) and the new fare (f_1) and on the initial level of journeys (T_0). The new level of trips will depend on the fare elasticity of demand for the service, and if the elasticity is known, then it would be possible to calculate the new level of traffic, T_1.

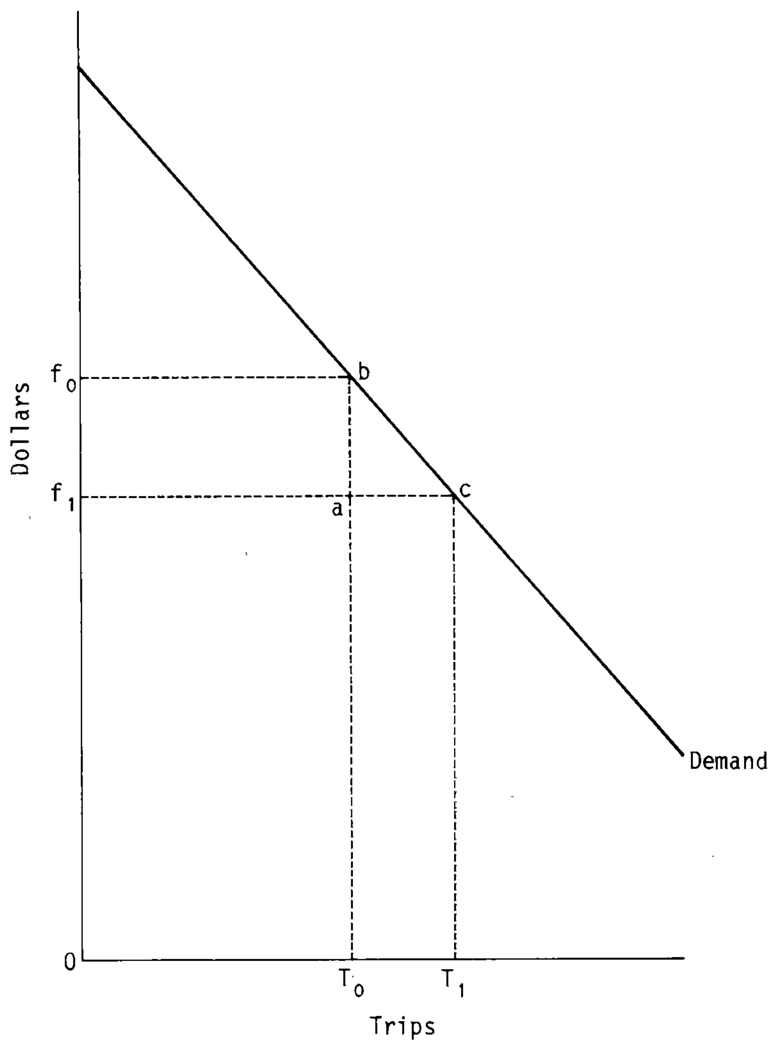

Figure 3.1-User benefits of a public transport fare reduction

The resulting benefits can be expressed very simply in terms of the own-fare elasticity of demand ε. From Figure 3.1 the gross (including transfer) benefits per extra dollar of subsidy equal

$$\frac{(f_1 \; f_0 \; ba - T_0 \; acT_1) + T_0bcT_1}{(f_1 \; f_0 \; ba - T_0acT_1)} \tag{3.1}$$

For a marginal (one unit) increase in bus patronage this can be written as approximately

$$\frac{(|\partial f/\partial T|.T - f) + f}{(|\partial f/\partial T|.T - f} = \frac{1}{1 - |\partial T/\partial f|.f/T}$$

$$= \frac{1}{1 - |\varepsilon|} \tag{3.2}$$

where $|\varepsilon|$ is the absolute value of the own-fare elasticity of demand.

Clearly then, these user benefits of fare subsidy depend on the demand elasticity; the more inelastic the demand, the steeper will be the slope of the curve through point b in Figure 3.1, and hence the smaller the benefit (the area below the demand curve and between the initial and final levels of trips). Hence there is a need to consider fare elasticity for public transport services in Australia.

Evidence on fare elasticity for public transport services

As is well-known, the demand for urban public transport services around the world is inelastic, with an average value discovered for many cities equal to -0.30. This is discussed more fully by *Transport and Road Research Laboratory* (TRRL 1980). Although this report contains some detailed evidence from Australia, estimates of own-fare elasticity of demand for urban public transport in Australia have been calculated by the Bureau of Transport Economics.

A Bureau of Transport Economics' (BTE 1977) study expressed demand for public transport per head of the population as a function of real bus or rail fares and other variables. When annual time-series data for the six State capital cities were pooled, fare elasticity values of -0.29 for bus and tram services and -0.35 for rail services were estimated. These elasticity values were used by the Commonwealth Grants Commission (1981, p. 258) to take account of differences in fare levels between States. More recent information is now available for some cities.

Sydney

The State Rail Authority appear, from oral advice, to believe that aggregate rail fare elasticity in Sydney is around -0.20 to -0.25. Some internal work has been undertaken within the Rail Authority and other work has been commissioned from an outside organisation but not yet completed. In 1978 a Bureau of Transport Economics' study (BTE 1978) estimated peak rail fare elasticity in Sydney to be -0.10 and off-peak elasticity to be -0.30. Hensher and Bullock's (1979) study of the effects of the 20 per cent rail fare reduction in Sydney in 1976 estimated the direct arc price elasticity for North Sydney commuters to be equal to -0.17. However, no recent direct evidence appears to be available on bus fare elasticity.

Melbourne

Singleton (1978) estimated fare elasticities for different public transport services in Melbourne as: all tram -0.30; all bus -0.11; Preston tram -0.28; and private bus -0.35. These estimates are based on measurement of the effects of fare increases in August 1975. The Melbourne Public Transport Study undertaken by Pak Poy and Associates (1980a) concluded on the basis of this and other evidence that the overall elasticity of demand with respect to fare increases in Melbourne was in the order of -0.30 to -0.40. The Victorian Metropolitan Transit Authority currently appears, from oral advice, to believe that aggregate fare elasticity for government bus and tram services is somewhere between -0.25 and -0.30 (with a wider range dependent on time of day and type of trip) that fare elasticity for private bus services is around -0.30, and that fare elasticity for rail services is around -0.20.

Brisbane

There does not appear to be any recent published study of fare elasticities in Brisbane. According to the 1984 Queensland submission to the Commonwealth Grants Commission, the following elasticity values have been adopted for planning purposes: bus peak -0.21; bus off-peak -0.45; bus all day -0.35; rail peak -0.15; rail off-peak -0.32; and rail all day -0.25. These figures are said to be based on internal research undertaken by the Metropolitan Transit Authority, but it is not clear what research methods were adopted or whether the results are accepted by the operators concerned (Brisbane City Council and Queensland Railways).

Adelaide

The Adelaide urban transport pricing study (Travers Morgan 1980c) carried out an analysis of Adelaide time series data and estimated elasticity values of -0.37 for bus and -0.40 for rail. Data did not permit disaggregation into peak and off-peak patronage, but the study suggests that an appropriate range of values for use in policy analysis would be -0.20 to -0.30 for peak and -0.40 to -0.50 for off-peak.

A 1982 study (Travers Morgan 1982) considered the impact of the August 1981 fare change on adult ticketholders. This before-and-after study estimated the arc elasticity of demand for adult travel to be -0.31 and the point elasticity to be -0.27. In their study of public transport pricing in Adelaide Amos and Starrs (1984) used information on proportions of travellers in peak and off-peak periods to disaggregate average elastcity figures. Assuming an average bus elasticity value of -0.30 they obtained figures for peak elasticity of -0.15 and off-peak of -0.45; for rail they reduced an assumed average figure of -0.35 to -0.20 for the peak and -0.57 for the off-peak.

Perth

The Perth Metropolitan Transport Trust (MPTT) appears to use a fare elasticity value of -0.30 for planning purposes. It has been suggested that rail fare elasticity in Perth may exceed bus fare elasticity because a relatively high proportion of travellers on the short rail network are choice (for example park-and-ride) passengers who could switch mode in response to a fare change. However, empirical studies of fare elasticity in Perth do not appear to have been undertaken.

Hobart

An elasticity value of around -0.30 has apparently been successfully used by the Metropolitan Transport Trust to predict the impact of bus fare changes on patronage and revenue. It is believed that demand by school children is relatively inelastic (around -0.20), that demand by pensioners has an elasticity value around -0.30, and that the elasticity of demand by adult passengers averages around -0.40. This last figure varies with length of trip from around -0.50 for short-distance trips (where walking is a possible alternative) to around -0.20 for the longest bus trips on the Hobart system.

Canberra

No estimates of bus fare elasticity appear to have been made for Canberra.

Fare reduction benefits in different cities

On the basis of the evidence from the different cities summarised above, the elasticity values set out in Table 3.1 can be used to

TABLE 3.1-FARE ELASTICITY VALUES ADOPTED FOR MEASURING SUBSIDY BENEFITS

	Bus fare elasticity			*Rail fare elasticity*		
City	*Aggregate*	*Peak*	*Off-peak*	*Aggregate*	*Peak*	*Off-peak*
Sydney	-0.30	-0.15	-0.45	-0.20	-0.10	-0.30
Melbourne	-0.30	-0.15	-0.45	-0.20	-0.10	-0.30
Brisbane	-0.35	-0.21	-0.45	-0.25	-0.15	-0.32
Adelaide	-0.30	-0.15	-0.45	-0.35	-0.20	-0.57
Perth	-0.30	-0.15	-0.45	-0.35	-0.20	-0.50
Hobart	-0.30	-0.15	-0.45	..	..	..
Canberra	-0.30	-0.15	-0.45	..	..	..

.. not applicable

demonstrate the benefits of overall fare changes and of fare changes in peak and off-peak periods.

From Equation 3.2 benefits per $1 of extra subsidy were therefore as follows:

Peak rail, Sydney and Melbourne	$1.11
Peak bus, Sydney, Melbourne, Adelaide, Perth, Hobart, Canberra	$1.18
Peak rail, Brisbane	$1.18
All day rail, Sydney and Melbourne	$1.25
Peak rail, Adelaide	$1.25
Peak bus, Brisbane	$1.27
All day rail, Brisbane	$1.33
All day bus, Sydney, Melbourne, Adelaide, Perth, Hobart, Canberra	$1.43
Off-peak rail, Sydney and Melbourne	$1.43
Off peak rail, Brisbane	$1.47
All day bus, Brisbane	$1.54
All day rail, Adelaide and Perth	$1.54
Off-peak bus, all cities	$1.82
Off-peak rail, Adelaide	$2.33

These figures show *gross* benefits per extra $1 of subsidy. Therefore, subtracting the cost of $1 subsidy the *net* benefits per extra $1 of subsidy lie in a range between 11 cents and $1.33. From these must be subtracted any increase in costs, which are considered in the subsequent sections.

BOARDING TIMES AND COSTS

Increases in passengers will impose some extra costs even where spare capacity exists. One such cost occurs where increases in passengers boarding buses or trams impose time delays on existing passengers. The level of such costs depends both on the physical time delay imposed, and on the valuation of increases in travel time for public transport passengers. The value of travel time is also an important input for the models in Chapters 4 and 5, and so is considered at some length later in this section.

Boarding (and alighting) times

There is an important distinction to be made between average and marginal times with respect to boarding times. Vehicle stop time will generally consist of an element of 'dead time', plus a boarding time related to the number of passengers boarding. Hence average boarding times will fall as the number of passengers boarding at a particular stop rises. Actual boarding times will depend on a number of factors, such as whether there is a one-person or conductor operation, the layout of the vehicle and its door operation. In addition with the slower one-person operation, times will depend on the ticketing system in operation. Boarding times will be shorter where users pre-purchase their tickets or where they pay a flat fare on the bus, especially when change is not provided. Boarding times will also depend on the ergonomic layout of the driver's cab and his ticket issuing and money handling facilities. The physical and mental agilities of the passengers themselves will be a further factor. Stop times will also depend on the number of people alighting, and the extent of the conflict between the people getting off, and those getting on, the vehicle[1].

In considering evidence on bus boarding and alighting times it is important to keep the distinction between average and marginal times clear. Cundill and Watt's (1973) survey of UK experience with one-operator, two-door vehicles, suggests marginal boarding plus alighting times per passenger of 5-6 seconds with graduated fare structures and 3.5-4 seconds with flat fare systems. A study undertaken by the Metropolitan Transit Authority (1980) in Brisbane discovered average boarding time per passenger to be equal to 7.97 seconds and estimated a relationship of the form:

Total stop time (seconds) = 8.23 + 5.19. (number boarding) **(3.6)**

1. For much more detailed discussions of these issues see Chapman (1975) and Cundill and Watts (1973).

Such a relationship implies marginal boarding time per passenger will equal 5.19 seconds. Actual Brisbane figures may now be slightly lower because of an increase in the proportion of pre-purchased tickets on the system.

Preliminary results of a study into boarding and alighting times in Adelaide kindly commissioned by the South Australian Department of Transport suggest a relationship of the form:

$$\text{Total stop time (seconds)} = 4.60 + 4.37.(\text{number of passengers boarding paying cash}) + 0.93.(\text{number of passengers boarding not paying cash}) + 1.36.(\text{number of passengers alighting from front door}) \quad (3.4)$$

A 1973 survey in Adelaide calculated average bus and tram boarding times in the morning peak at 4.35 seconds, while a 1981 study in Perth found a value per adult of 5 seconds.

Measurements by ACTION in Canberra for peak-period loading at interchanges when the proportion of passengers with pre-purchased tickets is highest and when the number of passengers boarding each bus is high suggest an average value as low as 2 seconds. The overall average for Canberra can be expected to be higher than this, but still below other bus systems because of the flat fare, farebox system and the high proportion of pre-payment in that city.

No direct measurements were available for Sydney and Hobart, though it has been suggested that similarity between fare systems and buses in Brisbane and Sydney may mean it is reasonable to assume similar values in these two cities. The nature of the fare structure and bus layout in Hobart suggest that average boarding times may be highest in this city.

Times in Melbourne are complicated by the mixture of tram and bus operation. The older W class trams which still account for nearly two-thirds of the fleet have fast boarding times because of the two wide doors and because passengers do not pay their fare or show their ticket as they board the vehicle. The newer Z class trams also have conductor operation, but all passengers must pass through the front entrance and pay their fare or show their ticket to the conductor who sits at a desk near the front of the car; while there is some circulating space in the area between the door and the desk, at times of high demand queues can build up outside the vehicle and prevent it moving away from the stop. However, as most stops are at intersections, additional passengers may still impose no extra delay if the vehicle is in any case delayed by an intersection traffic signal.

On the basis of all the above considerations the following marginal boarding plus alighting times were adopted in the calculations: Canberra 3 seconds; Melbourne 4 seconds; Adelaide and Perth 4.5 seconds; Brisbane and Sydney 6 seconds; and Hobart 7 seconds. These marginal delays are imposed on all existing passengers on the vehicle. From data on total vehicle-kilometres and journeys, and estimates of average journey length on each system, it was estimated that rough figures of average loadings on each vehicle for each publicly-operated system are: Sydney 18; Melbourne 16; Brisbane 12; Adelaide 11; Perth 10; Hobart 7; and Canberra 9. Hence an extra passenger imposes the following total delay: Sydney 108 seconds; Melbourne 64 seconds; Brisbane 72 seconds; Adelaide 50 seconds; Perth 45 seconds; Hobart 49 seconds; and Canberra 27 seconds. These delays must now be valued by reference to travel time values.

Value of travel time

This section deals with the values of travel time to be used throughout the present study. Travel time is usually valued in relation to average earnings, and this approach was adopted in the present study. The Australian Bureau of Statistics' November 1982 issue of *Survey of Earnings and Hours of Employees* (Australian Bureau of Statistics 1983a, p. 8) indicates average hourly earnings for all full-time adult non-managerial employees (male and female) of $8.43. This was rounded to $8.50 to yield an estimate of the average figure for 1982-83, and further adjusted to allow for earnings differentials between cities, using data on average hourly adult male earnings in the different capital cities from the May 1981 issue of *Survey of Earnings and Hours of Employees* (Australian Bureau of Statistics 1982). Non-working time was valued at one-quarter of hourly earnings, and working time was valued at hourly earnings plus a 10 per cent addition for overheads.

The proportions of vehicle occupants travelling in working and non-working time was derived from recent home interview surveys in Sydney and Melbourne. In Melbourne the 1978-79 Home Interview Travel Survey showed 4.8 per cent of all journeys were made 'on employer's business (including self-employed)' (Ministry of Transport Victoria 1981, p. 62). In the 1981 Sydney Region Travel Survey 4.7 per cent of all journeys were made by travellers 'on employer's business'. For car travellers this proportion was 6.13 per cent, for train passengers 1.65 per cent, and for bus passengers 1.33 per cent (State Transport Study Group of New South Wales 1982, pp. 6, 15, 31). As a simplification, it was assumed that 5 per cent of car travellers and 0 per cent of public transport users in each city were travelling in working time.

For truck drivers, the May 1981 earnings survey indicated hourly earnings for 'truck, van motor drivers, and deliverymen' as equal to 90 per cent of average male earnings (Australian Bureau of Statistics 1982, p. 21), and so commercial vehicle occupants' time was valued at a lower rate than that of car occupants travelling in working time.

The resulting in-vehicle travel time values used for each mode in each city are shown in Table 3.2.

Marginal delay costs

The marginal delay costs were calculated by multiplying total physical delays by the appropriate in-vehicle time values. The results of these calculations are shown in Table 3.3. At the margin the benefit of the extra trip by the additional passenger who imposes these delay costs is equal to the fare paid. The last column of Table 3.3 expresses the delay costs as a proportion of this fare. As can be seen, the estimated delay costs lie between 6 per cent and 21 per cent of the additional user benefits. Hence net benefits are still positive.

TABLE 3.2-VALUES OF IN-VEHICLE TRAVEL TIME PER VEHICLE OCCUPANT USED IN EVALUATON, 1982-83 PRICES

(Dollars per hour)

City	*Public transport*	*Car*	*Truck*
Sydney	2.18	2.55	8.42
Melbourne	2.12	2.48	8.42
Brisbane	2.10	2.46	8.42
Adelaide	2.02	2.36	8.42
Perth	2.06	2.41	8.42
Hobart	2.09	2.44	8.42
Canberra	2.13	2.49	8.42

Sources: ABS (1982 and 1983a). BTE calculations.

TABLE 3.3-MARGINAL DELAY COSTS PER ADDITIONAL BUS (OR TRAM) PASSENGER, 1982-83 PRICES

City	*Additional delay (seconds)*	*Value of additional delay (cents)*	*Delay costs as a proportion of benefit of additional trip*
Sydney	108	6.54	0.21
Melbourne	64	3.77	0.10
Brisbane	72	4.20	0.11
Adelaide	50	2.81	0.12
Perth	45	2.58	0.07
Hobart	49	2.84	0.07
Canberra	27	1.60	0.06

These results assume that there is no requirement to increase capacity. Where capacity levels on the public transport service have to be increased to cater for the extra trips, it is likely that costs will outweigh benefits. However, it is impossible to generalise about this factor without detailed knowledge of existing capacity constraints on the different systems. Consequently the final section of this chapter simply summarises information on public transport operating costs in Australia.

PUBLIC TRANSPORT OPERATORS' COSTS

Bus service costs

Table 3.4 summarises information on *average cost* per bus (or tram) kilometre for different operators in 1982-83 derived from statistics in annual reports. Bus costs vary between $1.47 per bus-kilometre in Perth and $2.81 in Sydney, with Melbourne tram costs being $4.16 per tram-kilometre. The much higher tram costs are due to a number of factors, including the costs of maintaining track and electricity supply equipment, the greater capital costs of the vehicles themselves, the slow average operating speed (partly due to the types of area where the trams run) and the absence of any one-person operation of tram services in the city. There are some differences in the treatment of capital costs by the various systems, with *capital charges* (in the forms of depreciation, interest and leasing) varying between 5 per cent of total expenditure in Canberra to 15 per cent of total expenditure in Melbourne. However, most of the differences in costs between the different bus systems are due to other factors, in particular manning levels, labour costs, service speeds (which in turn depend on traffic congestion), and the proportions of peak to other buses.

The basic unit of output in the bus industry is the vehicle itself, and hence one might expect more or less constant returns to scale with regard to costs per vehicle-kilometre. Indeed there is some evidence from the UK (Lee and Steedman 1970) of constant returns in urban bus operation. This would imply that marginal costs per bus-kilometre would be equal to average costs per kilometre. In practice, of course, particular types of service increase would be likely to have marginal costs above the average (especially in the peak) or below the average (especially in the off-peak). The levels of marginal cost of bus operation in Australia have been investigated most thoroughly in the Adelaide Bus Costing Study (Travers Morgan, 1980). This developed marginal costing models based on the number of buses required for a service improvement, crew hours and crew penalty hours, bus-kilometres and bus hours. Overhead costs (including maintenance costs) were allocated either to bus numbers or bus hours, while fuel, oil and tyre costs were allocated to bus-kilometres. The unit cost values derived are regularly updated. These values can then be used to assess the costs of particular types of service increase.

Suburban rail service costs

Set out below are recent estimates of average costs per train-kilometre. Little information is available on marginal costs per

TABLE 3.4-AVERAGE COST PER BUS OR TRAM KILOMETRE, 1982-83

City	*Average cost per bus-kilometre (dollars)*
Sydney, UTA buses	2.81
Newcastle, UTA buses	2.34
Melbourne, MMTB buses	2.18
Melbourne, MMTB trams	4.16
Brisbane, BCC buses	2.04
Adelaide, STA buses	1.92
Perth, MPTT buses	1.47
Hobart, MTT buses	1.60
Canberra, ACTION buses	1.66

Source: Various Annual Reports of Public Transport Authorities.

train-kilometre except in Adelaide, where extensive rail costing work has been undertaken, and in Melbourne.

Sydney
The State Rail Authority publishes each year in its Annual Report a breakdown of costs between suburban passenger, country passenger and freight services. For 1982-83 this yields a figure of around $14 as the average cost per train-kilometre of suburban services. These costs *exclude* any capital charges in the form of depreciation, interest, or leasing. However, they do include an allocation of infrastructure in the form of track, signalling, and structure maintenance costs between the three sectors to which costs are allocated.

Melbourne
In 1982-83 expenditure for Victorian Railways' suburban passenger and parcels network was $209 million. This is equivalent to $14.37 per train-kilometre. These figures exclude debt charges but they do make allowance for current infrastructure costs.

Brisbane
The Commonwealth Grants Commission (1982, p. 100) has published cost information based on direct costing and allocation of joint costs supplied by Queensland Railways for the Brisbane suburban system from 1977-78 to 1980-81. These costs include Queensland Railways debt charges, but they exclude debt charges on loans for electrification raised by the Metropolitan Transit Authority and make no allowance for the Commonwealth Government's contribution towards electrification. Excluding all debt charges the average cost per train-kilometre in 1981-82 was $10.50, or around $12.00 at 1982-83 prices.

Adelaide
The total cost of operating suburban rail services in Adelaide in 1982-83 was $37.3 million. These costs include depreciation and interest. The resulting average cost per train-kilometre is $9.59.

Perth
In 1982-83 the Metropolitan Passenger Transport Trust reimbursed Westrail the sum of $18.9 million for operating 1.77 million train-kilometres on the two lines in Perth. These reimbursed costs imply an average cost per train-kilometre of $10.68. These costs include depreciation, interest and leasing charges, but exclude costs incurred in 1982-83 in connection with the planned re-opening of the Perth to Fremantle line.

The figures of average cost per train-kilometre lie in a range between about $9 to about $14. The differences between the figures will reflect many factors, including average train length (Adelaide in particular operates relatively short trains), the number of stations per kilometre of route, wage rates, and the methods used to allocate track and signalling costs to suburban services and the extent to which suburban services share these facilities with other types of traffic. Because of differences in definitions the figures from the different cities are not directly comparable. However, they suggest an ordering from highest to lowest cost of:

- Melbourne and Sydney
- Brisbane
- Perth
- Adelaide

which does not seem unreasonable.

If the size of the rail network (in terms of route length, number of stations etc) were not to be changed, then one would expect marginal costs per train-kilometre to lie below average costs per train-kilometre because of the well-known economies of traffic density on rail systems.

Extensive information on the marginal costs of rail services in Adelaide is available from the *Adelaide Rail Costing Study* (Travers Morgan 1980). The aim of this study was to provide marginal costs which could be readily up-dated to provide an on-going planning tool to consider changes in rail services. The study measured operating costs only, and did not consider capital charges. A series of unit costs were developed in order to be able to derive the marginal costs of any particular service change, such as a change in train-kilometres operated on the existing system, or a change in the network over which services were operated for all or part of the day[1].

Table 3.5 shows marginal costs per train-kilometre derived from the study's worked example of the costs of increasing services on the 39.8 kilometre Adelaide to North Gawler route. The table shows how costs vary by time of day and size of train. The peak period costs show the marginal cost of an extra return trip run in both morning and afternoon peak periods. These costs include extra crew costs (1 and 2

1. Unit cost figures for Victorian Railways suburban operations in 1979-80 have also been derived (Pak Poy 1980b).

car trains have 2 crewmen, and 3 or more car trains 3 crewmen), costs of servicing and cleaning railcars, costs of repairs to railcars, fuel, and marginal permanent way maintenance costs. The off-peak costs include only fuel, railcar repair costs, and marginal permanent way maintenance costs; since crews do not work broken shifts, there will always be spare crews available between peaks. Evening costs would be only slightly above off-peak costs, whereas weekend costs for two extra return trains would be fairly similar to peak costs. In 1978-79 *average* costs per train-kilometre on the system (excluding depreciation or interest charges) were $6.73, so marginal costs clearly do lie some way below average costs.

TABLE 3.5-MARGINAL COSTS PER WEEKDAY TRAIN-KILOMETRE: ADELAIDE, 1978-79 PRICES

(Dollars)

Train size, number of cars	*Marginal cost per train-kilometre*	
	Peak	*Off-peak*
1	2.13	0.51
2	2.30	0.56
3	3.54	1.07
6	5.20	2.14

Note: Figures are derived for the Adelaide to North Gawler route.

Source: Travers Morgan (1980).

CONCLUDING REMARKS

This chapter has considered the benefits of subsidising reduced public transport fares. Where operators have spare capacity these benefits will be positive. However, where additional capacity has to be installed, the benefits of additional trips induced by lower fares will have to be compared with the costs to the operator of increasing capacity. These costs would have to be considered on a case-by-case basis, using the type of costing model which is able to reflect marginal changes in the operation of the particular public transport system under consideration.

CHAPTER 4-BENEFITS OF IMPROVING PUBLIC TRANSPORT SERVICE LEVELS

This chapter considers the measurement of the benefits of service improvements that occur through increased frequency of bus, tram or rail services. The primary impact of improved frequency is on waiting times. A model evaluating the benefits and costs of frequency improvements is outlined below. This model is then used to estimate benefits of frequency improvements on nine bus and tram systems and on five rail systems.

A FREQUENCY BENEFIT MODEL

Figure 4.1 illustrates the benefits of an increase in frequency and the consequent reduction in waiting times. Initially the generalised cost per trip of a public transport journey is g_0. This is made up of the fare, f_0, and time, part of which is in-vehicle time, part waiting time, and part walking time. An increase in frequency will reduce the waiting time component, and hence the generalised cost per trip falls to g_1. Consequently there is an increase from T_0 to T_1 in the number of public transport trips made.

The benefits of the increase in frequency are equal to the waiting time savings for existing travellers (area g_1 g_0 ab), benefits to new public transport users (area bac), and additional revenue to the operator from these new trips (area T_0 de T_1). To be offset against these benefits are the costs to the operator of the additional vehicle-kilometres that have to be operated to secure the increase in frequency (allowing for any changes in vehicle speeds due to changes in boarding times). In addition, in-vehicle times for passengers may change as the number of passengers boarding any individual vehicle changes in response to the changes in total vehicle-kilometres operated and total passengers carried. A study by Wilbur Smith and Associates (1977) for the Metropolitan (Perth) Passenger Transport Trust recommended using this type of cost-benefit methodology for appraising increases in the frequency of bus services. However, the proposed methodology appears to have omitted a major source of benefits (revealed by Figure 4.1) namely the time savings to existing (as opposed to new) bus passengers.

The methodology outlined in Figure 4.1 can be applied by considering the costs and benefits of increasing vehicle-kilometres operated on an individual route or system by one unit. This can be illustrated by reference to an increase in frequency on a bus service. Such an increase will lead to an increase in operator's costs equal to the marginal cost per bus-kilometre, $\partial C/\partial B$, where C is the operator's total costs and B the total bus-kilometres operated. However, if passenger numbers are sensitive to frequency, the increased frequency will lead to some gain in revenue to offset the increased operating

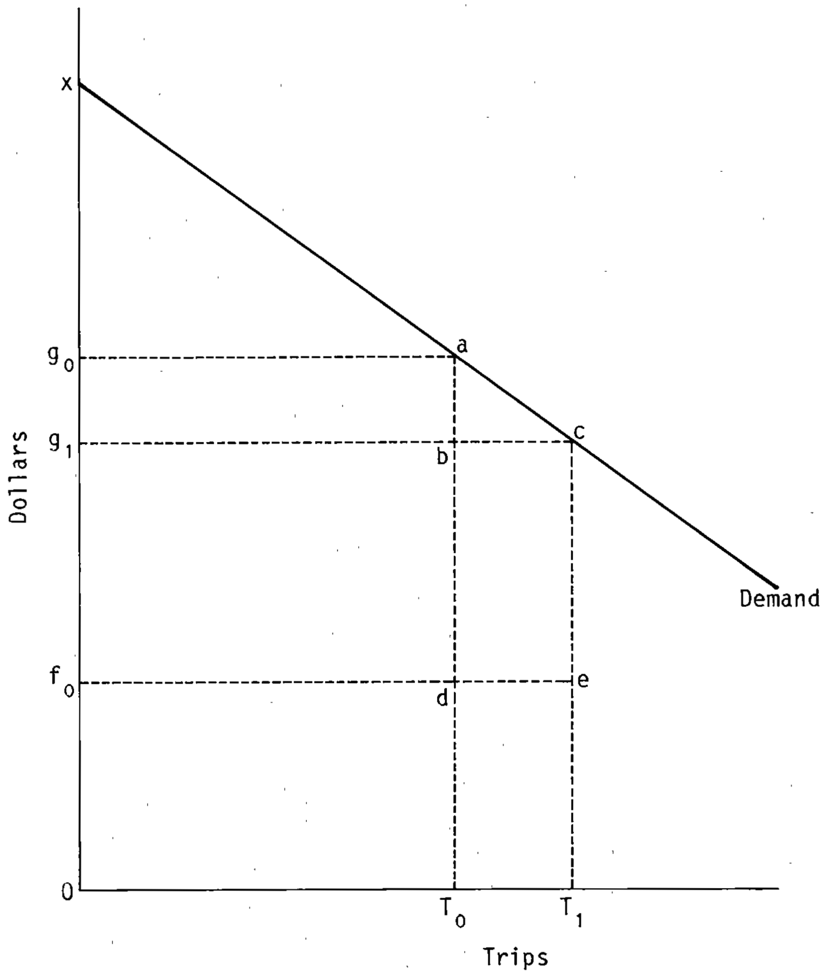

Figure 4.1-Benefits and costs of a service improvement

costs. With an unchanged fare level this increase in revenue will equal

$$\partial R/_{\partial B} = \partial T/_{\partial B} \cdot f \qquad (4.1)$$

where f = fare per trip.

Expressing Equation (4.1) in terms of service elasticities gives

$$\partial R/_{\partial B} = \varepsilon_S \cdot T/_{B} \cdot f \qquad (4.2)$$

where ε_S= service elasticity, here defined as bus-kilometre elasticity $\partial T/\partial B.\ B/T$

or $\dfrac{\text{proportional change in bus trips}}{\text{proportional change in bus kms}}$

T/B = trips per bus-kilometre.

Combining the cost and revenue components the change in subsidy, dS, required to finance the increase in service level is

$$dS = \partial C/_{\partial B} - \varepsilon_S \cdot T/_{B} \cdot f \qquad (4.3)$$

For such a (marginal) change the benefits will be equal to the average reduction in waiting time multiplied by the existing number of passenger trips. This can be expressed as

$$\left|\frac{\partial w_S}{\partial B}\right| \cdot \alpha_{w_S} \cdot T \qquad (4.4)$$

where w_S = average waiting time per trip, in seconds
α_{w_S}= value of waiting time per second

$\partial w_S/_{\partial B}$ shows the impact of a one unit increase in bus kilometres on average waiting time.

(Note that the absolute value of $\partial w_S/_{\partial B}$ is taken since an increase in bus-kilometres causes a *reduction* in waiting time, which in turn is a *positive* benefit to the passenger).

Waiting time on a public transport network depends primarily on frequency or headway. If frequency, q, is expressed in terms of number of buses per hour and headway, h, in minutes, then

$$h_m = 60/_{q} \qquad (4.5)$$

where h_m = headway in minutes, (ie headway is the average time between buses travelling in the same direction on a particular route)

q = frequency in buses per hour, (ie frequency is the number of buses travelling in a particular direction passing a fixed point on the network in a period of one hour).

At low headways and high frequencies travellers can be expected not to consult timetables, and so can be expected to arrive randomly at bus stops. In such circumstances average waiting time will simply be equal to half the headway as long as the public transport service provides a reliable service with constant headway[1]. However as headways rise and frequencies fall, passengers are likely to try to time their arrivals at bus stops to reduce waiting time; hence average waiting time will be less than half the headway. Although there is some data on actual waiting times for urban public transport services in Australia (eg Metropolitan Transit Authority 1983; Nairn 1978) the best study relating waiting times for bus services to headway is one carried out in Manchester, England (Seddon and Day, 1974). The study measured actual bus passenger waiting times at 16 different locations and times of the day for services with headways varying from 4 to 30 minutes. Passenger arrivals at stops were found to be random up to a mean headway of 10-12 minutes. Average waiting times were expressed as a function of headway, and a quadratic relationship estimated. This took the form:

$$w_s = 11.39 + 0.49\ h_s - 0.00009\ h_s^2 \qquad \textbf{(4.6)}$$

where w_s = average waiting time in *seconds*;
h_s = average headway in *seconds*.

Table 4.1 shows the average waiting time values implied by different headway and frequency levels. As can be seen, average waiting time is close to half of headway up to headways of about 7.5 to 10 minutes, but then falls as a proportion of headway.

For the purposes of this exercise it is necessary to know how waiting time changes with changes in headway. From Equation 4.6

$$\partial w_s / \partial h_s = 0.49 - 0.00018 h_s \qquad \textbf{(4.7)}$$

The last column of Table 4.1 shows values of this derivative for

1. See *Transport and Road Research Laboratory* 1980, pp. 131-2 for a discussion of average waiting times on high-frequency low-reliability services.

different levels of headway/frequency.

In order to determine the relationship between waiting time and bus-kilometres, the impact of changes in bus-kilometres on average headway, $\partial h/\partial B$, is needed. In a public transport system which operates a fixed network of routes, and whose total unduplicated length is equal to L route kilometres, average frequency, q, will equal:

$$q = \frac{B}{L \times OH \times 2} \tag{4.8}$$

where q = average frequency per hour;
B = annual bus kilometres;
L = unduplicated route kilometres; and
OH = operating hours, i.e. number of hours during the year for which the system is operating.

Therefore q shows the average number of buses per hour passing a given point in each direction. Average headway is then

$$h_m = {}^{60}/_{q} = \frac{60\ (L \times OH \times 2)}{B} \tag{4.9}$$

$$h_s = {}^{3600}/_{q} = \frac{3600\ (L \times OH \times 2)}{B} \tag{4.10}$$

TABLE 4.1-BUS PASSENGER WAITING TIMES, HEADWAYS AND FREQUENCIES

Headway (minutes)	*Frequency (buses/hour)*	*Average waiting time w_m (minutes)*	*Waiting time / Headway*	*w_s/ h_s (seconds)*
2	30	1.16	0.58	0.47
3	20	1.60	0.53	0.46
4	15	2.05	0.51	0.45
5	12	2.49	0.50	0.44
7.5	8	3.54	0.47	0.41
10	6	4.52	0.45	0.38
15	4	6.27	0.42	0.33
20	3	7.75	0.39	0.27
30	2	9.91	0.33	0.16

Source: Waiting times derived from the formula
$w_s = 11.39 + 0.49\, h_s - 0.00009\, h_s^2$
from Seddon and Day (1974).

From Equation 4.10

$$\partial h_s/_{\partial B} = - \frac{3600\ (L \times OH \times 2)}{B^2} = - \frac{h_s}{B} \tag{4.11}$$

Now the change in waiting time as a result of a one unit increase in bus-kilometres can be expressed as

$$\partial w_s/_{\partial B} = \partial w_s/_{\partial h_s} \cdot \partial h_s/_{\partial B} \tag{4.12}$$

From Equations 4.7 and 4.11

$$\partial w_s/_{\partial B} = - (0.49 - 0.00018h_s)\ h_s/_B \tag{4.13}$$

The marginal net benefit per $1 of subsidy devoted to increasing frequencies on a public transport network can now be considered. From Equations 4.4 and 4.3 the marginal net benefit per $1 of subsidy is

$$\frac{\left|\frac{\partial w_s}{\partial B}\right| \cdot \alpha_{w_s} \cdot T + \varepsilon_s \cdot \frac{T}{B} \cdot f - \frac{\partial C}{\partial B}}{\frac{\partial C}{\partial B} - \varepsilon_s \cdot \frac{T}{B} \cdot f} \tag{4.14}$$

Substituting this expression for $\partial w_s/\partial B$ from Equation 4.13, gives

$$\frac{(0.49 - 0.00018h_s) \cdot \frac{h_s}{B} \cdot \alpha_{w_s} \cdot T}{\frac{\partial C}{\partial B} - \varepsilon_s \cdot \frac{T}{B} \cdot f} - 1 \tag{4.15}$$

$$= \frac{(0.49 - 0.00018\ h_s) \cdot h_s \cdot \alpha_{w_s}}{\frac{\partial C}{\partial B} \cdot \frac{B}{T} - \varepsilon_s \cdot f} - 1 \tag{4.16}$$

Equation (4.16) therefore shows the marginal *net* benefit per $1 spent on frequency improvements. The term on the left hand side of the equation shows the marginal *gross* benefit.

This equation shows that the benefits of a frequency improvement on a route or a system can be expressed as a function of the following variables:

(i) α_{w_s} - the value of waiting time. Increases in the value which passengers place on waiting time obviously *increase* the value of service improvements.

(ii) h_s- existing headway on the service or system. The poorer is the present level of service, the *greater* will be the benefits of service improvement. (Since increases in headway would never reduce waiting times, Equation 4.7 is only valid as long as $h_s < 2722$, ie for average headways below 45 minutes).

(iii) $\partial C/\partial B$ - the marginal cost per bus-kilometre of the service improvement. The higher is the cost of increasing the service level, the *lower* will be the benefits.

(iv) T/B - passenger journeys per bus-kilometre on the route or system (a measure of service utilisation). Benefits of service improvement are *positively* related to this measure of the existing level of utilisation of the route or system.

(v) ε_S- service elasticity in the form of the elasticity of passenger journeys with respect to bus-kilometres. Benefits of service improvement are *positively* related to this elasticity.

(vi) f - average fare per trip, assuming that additional passengers attracted by the service improvement are carried at the route-wide or system-wide average fare. Benefits of service improvement are *positively* related to this fare.

Equation 4.16 can therefore be used either at the level of an individual route or at a system level. For this study it is used to compare the benefits of service improvement on different Australian systems.

BUS SYSTEMS

This section considers the potential benefit of service improvement on the nine public transport systems described in Chapter 2 using data for 1982-83.

Results of applying Equation 4.16 to these urban systems are presented in Tables 4.2 and 4.3. A detailed discussion of the derivation of these figures is provided below.

Value of waiting time is derived from the travel time values discussed in Chapter 3. All public transport users are assumed to be travelling in non-working time. Waiting time is valued at half average earnings, that is at twice the value adopted for in-vehicle time[1]. The

1. Relative values of waiting and in-vehicle time are discussed in Transport and Road Research Laboratory 1980, pp. 140-1.

resulting values of waiting time per *minute* are shown in the first column of Table 4.3.

Average headways are derived from data on each system using Equations 4.8 and 4.9. Data on total bus (or tram) kilometres operated by each system are available from annual reports, as is information on unduplicated route length. This information is reproduced in Table 4.2. Average frequency levels are derived on the assumption that each system operates for some 5000 hours in the year. This underestimates actual operating hours, but makes some rather crude allowance for low frequency levels in evening and weekend periods. The resulting average frequency and headway levels are shown in Table 4.2, and the headway levels reproduced in the second column of Table 4.3.

The value of marginal cost per bus-kilometre, C/ B, will depend on the particular frequency improvement under consideration and, in particular, on whether peak or off-peak services are being increased.

The figures in the third column of Table 4.3 are of average costs per bus kilometre derived from annual reports for the different systems and are discussed in Chapter 3. The benefits of bus frequency

TABLE 4.2-AVERAGE FREQUENCY AND HEADWAY LEVELS ON AUSTRALIAN URBAN BUS SYSTEMS, 1982-83

City/system	*Annual distance travelled* B *(million km)*	*nduplicated route-distance* L *(km)*	*Average frequency* q *(no/hr)*	*Average headway* h_m *(minutes)*
Sydney, UTA buses	57.945	860.27	6.74	8.91
Newcastle, UTA buses	8.026	248.96	3.22	18.61
Melbourne, MMTB buses	13.311	220.8	6.03	9.95
Melbourne, MMTB trams	24.202	302.2	8.01	7.49
Brisbane, BCC buses	22.310	676	3.30	18.18
Adelaide, STA buses	38.453	965.14	3.98	15.06
Perth, MPTT buses	42.450	1627.6	2.61	23.00
Hobart, MTT buses	7.618	260.43	2.93	20.51
Canberra, ACTION buses	11.555	448.7[a]	2.58	23.30

a. 1984 figure.

Sources: Various Annual Reports of Public Transport Authorities. BTE calculations.

TABLE 4.3-BENEFITS PER DOLLAR SPENT ON FREQUENCY IMPROVEMENTS ON AUSTRALIAN URBAN BUS SYSTEMS, 1982-83

City/system	*Value of waiting time* a_w *(c/minute)*	*Average headway* h_m *(minutes)*	*Average cost per bus-km (dollars)*	*Passenger journeys per bus km T/B*	*Service elasticity* e_s	*Average fare per journey f (dollars)*	*Benefits per dollar spent on frequency*	
							MC equal to AC (dollars)	*MC equal to 80% AC (dollars)*
Sydney, UTA buses	7.27	8.91	2.81	2.98	0.41	0.33	0.32	0.41
Newcastle, UTA buses	7.08[a]	18.61	2.34	1.98	0.54	0.25	0.36	0.47
Melbourne, MMTB buses	7.05	9.95	2.18	1.93	0.40	0.38	0.27	0.36
Melbourne, MMTB trams	7.05	7.49	4.16	4.50	0.40	0.36	0.28	0.36
Brisbane, BCC buses	6.98	18.18	2.04	2.00	0.53	0.39	0.46	0.61
Adelaide, STA buses	6.74	15.06	1.92	1.75	0.49	0.23	0.34	0.43
Perth, MPTT buses	6.87	23.00	1.47	1.27	0.60	0.35	0.40	0.53
Hobart, MTT buses	6.96	20.51	1.60	1.39	0.57	0.38	0.41	0.55
Canberra, ACTION buses	7.08[a]	23.30	1.66	1.41	0.60	0.32	0.40	0.52

a. Note that in the absence of any data on earnings in Newcastle and Canberra, hourly earnings in these two cities have had to be assumed equal to the national average.

improvements were considered, firstly when marginal costs equal average costs, and secondly when marginal costs are equal to 80 per cent of average costs.

Passenger journeys per bus-kilometre can be derived from information on total journeys and total bus-kilometres operated, and are shown in the fourth column of Table 4.3.

Average fare per journey is equal to total revenue (excluding repayment for concessionary fares) divided by total passenger journeys. Data on passenger revenue were extracted from annual reports and information on Government compensation for concessionary passengers obtained, where necessary, from operators.

International evidence on *service elasticities* for urban public transport services has been summarised by Lago et al (1981) and by the Transport and Road Research Laboratory (1980). It was considered that in the case of a public transport system with a fixed route network, average frequency or headway was proportional to total kilometres operated and hence in absolute terms vehicle-kilometre elasticity, frequency elasticity and headway elasticity will be equal[1]. The international collaborative study on factors determining public transport patronage published by the Transport and Road Research Laboratory (1980 pp. 129-155, 275-279), outlines some methods available for estimating vehicle-kilometre elasticity. The three methods are:

(i) time series analysis of patronage and independent variables for a particular area, operator or route;

(ii) cross-section analysis of data for a sample of areas, operators or routes; and

(iii) before-and-after studies of the impact of changes in vehicle-kilometres in one or more particular cases.

Most studies employ aggregate data, but a disaggregate approach to mode choice can also be used to derive the relevant elasticities from individual choice data.

The TRRL survey notes that aggregate time-series studies of patronage

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1. Since it has been assumed that waiting time is not proportional to headway (see Equation (4.6)), waiting time elasticity will differ from these three service elasticities.

in Australia, France, the UK and the USA found values of the elasticity with respect to vehicle-kilometres in a range between 0.2 and 1.2, with a central value around 0.7, whereas aggregate cross-sectional studies produced a range between 0.6 and 1.4. However, both of these methods suffer from the difficulty of disentangling cause and effect, since it is usually not clear whether the kilometre-elasticity results are picking up the impact of service level changes on patronage (which is the intention), or the impact of changes in patronage on the level of capacity which operators decide to provide. Hence the above service elasticity values are likely to be over-estimated. Indeed, before-and-after studies of headway elasticities, which do not suffer from this problem, have produced service elasticity values in a range from 0.2 to 1.0, centering around 0.5.

In addition, a consideration of generalised cost also suggests lower values than those obtained from aggregate cross-section and time-series studies. Consequently, the international survey concludes

> ...whereas there is a large body of evidence to fix average fare elasticities at -0.3 (in the range -0.1 to -0.6), there is very much less reliable evidence about the effects of service, but the elasticity relative to scheduled vehicle-kilometres is likely to be, on average, 0.4 or 0.5, in a somewhat wider range' (*Transport and Road Research Laboratory* 1980, p. 144).

However, in addition 'it is likely that service elasticity is higher for longer headways' (Transport and Road Research Laboratory 1980, p. 155). The latter conclusion was also reached by Lago et al (1981, pp. 101, 114).

In Australia, elasticities of bus and rail demand per head of the population with respect to bus and train-kilometres per head were derived using annual time-series data for the State capital cities by the Bureau of Transport Economics (1977, pp. 93-102). When service elasticities were estimated with pooled cross-section and time-series data, in an aggregate equation incorporating dummy variables to reflect inter-city differences, the resulting value of service elasticity for bus was 0.63 and for rail 1.10. The elasticities were also estimated separately for the six cities for each mode. Bus service elasticities were all positive, in a range between 0.34 and 1.11. Rail service elasticities were also positive, in a range between 0.44 and 1.26.

Service elasticity data disaggregated by city in this way are ideal for the purposes of the present study, but unfortunately the difficulty of disentangling cause-and-effect in time-series studies noted above, together with other difficulties with these estimates, mean that it would be misleading to rely on these values. Nevertheless, results on the implied benefits of service improvements based on these BTE estimates are presented later in this chapter.

Further work on kilometre-elasticities has been carried out by Singleton and his associates in Melbourne (Ove Arup Transportation Planning 1981 and Singleton et al, 1982). Monthly time-series data were used to estimate service elasticities for MMTB tram and bus services (disaggregated by depot and to some extent by ticket type), for Victorian Railways suburban services, and for private bus services (disaggregated by route). It did not prove possible to estimate a statistically significant value of service elasticity for rail services, but weekday kilometre elasticity values in a range from 0.7 to 1.4 were derived for Government tram and bus services and kilometre elasticity values in a range from 0.03 to 1.24 were derived for individual private bus routes. Again problems of possible over-estimation arise, and the researchers concluded that for planning purposes short-term vehicle-kilometre and frequency elasticities of 0.3 to 0.4 for work journeys and 0.4 to 0.5 for non-work journeys should be adopted in Melbourne. They also suggested that higher than average values would be appropriate for relatively infrequent or unreliable services, and vice versa for relatively frequent services.

There appears to be very little other satisfactory recent information available (see Ove Arup 1981, p.4). However, the effects of increases of off-peak bus frequency have been monitored in Adelaide and Perth. In Adelaide in 1975 off-peak frequency along the Glen Osmond-Novar Gardens route was increased from 3 to 6 per hour for an experimental twelve-month period and the results carefully monitored. 'The result of the experiment was quite conclusive...', the frequency increase 'did not result in any significant increase in public transport patronage' (Foley 1976, p.15). New off-peak 'Hi-Frequency' services introduced since November 1981 in Perth have led to some patronage gains (Metropolitan (Perth) Passenger Transport Trust 1983, pp. 6,8), although other services in the same areas have lost traffic.

In the following analysis the service elasticity value averaging 0.4, recommended in Melbourne by Ove Arup (1981), and suggested as an international average by the TRRL (1980) was used. This value was also used for the other Australian capital cities except insofar as average headway levels differ between the cities. Some slight adjustment was therefore made to the service elasticity values used for the different cities and shown in the fifth column of Table 4.3. This adjustment was carried out by assuming a service elasticity value of 0.6 for Perth and adjusting the other cities' service elasticities pro rata to the average headway values in the second column.

Benefits per dollar spent on frequency improvement were then computed, and the results are shown in the sixth and seventh columns of Table 4.3. Column six shows results when marginal costs per bus-kilometre. were assumed equal to average costs, and column seven shows results when marginal costs were assumed equal to 80 per cent of average costs. The figures in the sixth and seventh columns are gross rather than net benefits per extra $1 of subsidy, and since they are all less than one, this indicates that increases in frequency levels on all the systems would lead to a reduction in net social benefits whichever of the two assumptions about marginal costs are adopted. Though some care should be taken when considering the individual figures, the case for service improvements appears weakest in Melbourne and strongest in Brisbane. In Chapter 5, it will be shown that increases in bus-kilometres will often *add* to road congestion, since the effects of the diversion of private car users to buses may be outweighed by the effects of the increased bus-kilometres operated. Hence it appears that there is a strong case on efficiency grounds for reducing service levels.

As a check on the sensitivity of these results to the value of service elasticity adopted, Table 4.4 contrasts the benefit and elasticity values with the results which would be obtained if the BTE bus service elasticity values discussed earlier were used. As can be seen from the table, the only major difference in the results is that for Sydney. However, the BTE bus service elasticity value of 1.11 estimated for Sydney does appear to be unrealistically high.

RAIL SYSTEMS

This section considers the potential benefits of service improvements on the five suburban rail systems in Australia.

The same model used to evaluate frequency improvements for bus services was used to evaluate frequency improvements for rail services. A difficulty with this approach was that while the relationship between headway and waiting time used in the model was derived from empirical observations of *bus* passengers, rail passengers may behave differently (for example if rail services were more reliable than bus services). However, no information appears to be available on the relationship between rail headways and waiting times.

Value of waiting time - the same city-specific values as for bus services are used.

Average headways are calculated using the same method as for bus and tram systems.

Sydney

A problem arises for New South Wales in that State Rail Authority suburban passenger journeys and train-kilometre statistics cover a wide geographical area, from Kiama and Moss Vale in the south to Lithgow in the west and to Dungog and Singleton (the northern limits of the Newcastle suburban network) in the north. This network consists of some 830 kilometres of route, of which 315 kilometres are the Sydney suburban network, 330 kilometres the Sydney inter-urban network, and 215 kilometres the Newcastle suburban network (the individual lengths exceed the overall total because the Sydney and Newcastle areas overlap). Both the inter-urban and Newcastle networks are much less intensively serviced than the Sydney suburban network and so the average headway measure has been based on an estimate of train-kilometres in the Sydney suburban area. This was calculated by subtracting a rough estimate derived from timetables of Newcastle and inter-urban train-kilometres from the 1981-82 figure of total New South Wales suburban train-kilometres. In addition, night train-kilometres in Sydney were also subtracted from the total train-kilometres figure (see Commonwealth Grants Commission 1982, p. 61, for the method used to derive night train-kilometres).

TABLE 4.4-SENSITIVITY OF SERVICE IMPROVEMENT BENEFITS TO THE VALUE OF SERVICE ELASTICITY

	Service elasticities		*Benefits per dollar spent on service improvements (MC per bus-km equals AC per bus-km)*	
	Table 4.3	*BTE estimates*	*Based on elasticities in Table 4.3*	*Based on BTE elasticity estimates*
Sydney bus	0.41	1.11	0.32	0.44
Melbourne bus	0.40	0.49	0.27	0.28
Melbourne tram	0.40	0.49	0.28	0.29
Brisbane bus	0.53	0.67	0.46	0.49
Adelaide bus	0.49	0.54	0.34	0.35
Perth bus	0.60	0.86	0.40	0.45
Hobart bus	0.57	0.34	0.41	0.38

Melbourne
In 1982-83 the electrified suburban network in Melbourne consisted of 310 kilometres of route. In addition, some diesel services are also included in the suburban network. The average frequency calculation was based on the electric route network and electric suburban passenger train-kilometres in 1982-83.

Brisbane
In 1982-83, 4.466 million train-kilometres were operated over the 197 kilometre suburban route network.

Adelaide
In 1982-83, 3.894 million train-kilometres were operated over the 152 kilometre network.

Perth
In 1982-83, two suburban lines, with an unduplicated route length of 44 kilometres, were operated. Total train-kilometres were 1.769 million.

Average headway estimates for the five systems are shown in the second column of Table 4.5.

Marginal cost per train-kilometre - as in the case of buses, this will vary with the type of service improvement under consideration. For illustrative purposes, and to test the sensitivity of the results to differences in marginal costs, it was assumed that figures for each system were equal to either approximately 50 per cent or approximately 80 per cent of average costs per train-kilometre quoted in Chapter 3.

Journeys per train-kilometre were derived from figures in annual reports or from information from operators.

Fare per journey was derived from annual report figures of passenger revenue, less estimates of repayments for concessionary revenue, and annual report figures of passenger journeys.

Service elasticities - apart from the BTE (1977) study, little information is available on rail service elasticities. Lago et al (1981, p. 114) note that bus and commuter-rail headway elasticities appear to be similar, though this conclusion is based on a very limited number of (mainly US) studies. In this analysis the same vehicle-kilometre elasticities were taken as applied to buses, with values again adjusted to make some allowance for higher elasticity values at lower frequency levels.

TABLE 4.5-BENEFITS PER DOLLAR SPENT ON FREQUENCY IMPROVEMENTS ON AUSTRALIAN URBAN RAIL SYSTEMS, 1982-83

	Value of waiting time a_w (c/minute)	Average headway h_m (minutes)	Marginal cost[a] (low cost assumption) MC (dollars/train-km)	Passenger journeys per train-km	Train-km elasticity e_s	Average fare (dollars/journey)	Benefits per dollar spent on frequency improvements	
							MC equal to 80 per cent AC (dollars)	MC equal to 50 per cent AC (dollars)
Sydney/Newcastle,								
NSW SRA	7.27	9.95[b]	7.00	9.30[b]	0.42	0.53	0.19	0.52
Melbourne, V/Line	7.05	13.43	7.00	5.51	0.47	0.88	0.20	0.38
Brisbane, QR	6.98	25.39	6.00	7.42	0.63	0.39	0.36	0.68
Adelaide, STA	6.74	23.42	4.50	3.70	0.60	0.31	0.18	0.36
Perth, MPTT	6.87	14.92	5.25	3.76	0.49	0.41	0.17	0.28

a. For illustrative purposes taken to be equal to approximately half average system-wide costs per train-kilometre.
b. Based on 1981-82 information.

The sixth and seventh columns of Table 4.5 show the computed net benefits per $1 spent on frequency improvements on rail services. Column six shows results for the higher cost assumption (marginal costs equal 80 per cent of average costs) and column seven shows results for the lower cost assumption (marginal cost equals 50 per cent of average costs). As for bus services, all the marginal gross benefit figures were less than one, indicating that frequency reductions rather than improvements would be appropriate. Given the difficulties of determining the precise values for marginal costs, it would be difficult to make any detailed comparison of the bus and rail results.

CHAPTER 5-PUBLIC TRANSPORT SUBSIDIES AND THE REDUCTION OF HIGHWAY CONGESTION

This chapter outlines the measurement of the benefits of changes in highway congestion. Estimates of these benefits are presented for four cities for which data in the most suitable form are available. These cities are Sydney, Melbourne, Brisbane and Adelaide. Although the choice of these cities was based on data availability, congestion is in any case likely to be less of a problem in Canberra and Hobart, and probably also in Perth.

THE MODEL

Figure 5.1 outlines the basic model for estimating the benefits that result through the reduction of road congestion that occurs as a result of an increase in public transport subsidies. The vertical axis shows the generalised cost (including time costs) per trip on one lane of a particular section of highway. The marginal private cost (MPC) curve shows the average cost per trip, and the marginal social cost (MSC) curve shows the marginal cost of each additional trip. F_0 is the initial flow of vehicles on the lane, and this results in a generalised cost of c_0 per vehicle. If public transport subsidies reduce the traffic flow from F_0 to F_1, there is a fall of $(c_0 - c_1)$ in the generalised cost per vehicle and hence benefits to all the remaining traffic, F_1, equal to the area c_1c_0ab.

If the reduction of highway traffic occurs as a result of a reduction in the public transport fare, f, (rather than as a result of an increase in public transport service levels) then the change in road traffic, dF, can be written as:

$$dF = \frac{\partial F}{\partial f} \cdot df = F \cdot \varepsilon_{fx} \cdot \frac{df}{f} \qquad (5.1)$$

where F = traffic flow on the lane;

$\varepsilon_{fx} = \frac{dF}{df} \cdot \frac{f}{F}$ = cross-elasticity of demand for private vehicle trips with respect to public transport fare, i.e. $\dfrac{\text{proportional change in private vehicle trips}}{\text{proportional change in public transport fare}}$; and

df/f = proportional change in public transport fare.

The resulting change in generalised cost per vehicle trip, dc, is equal to

$$dc = \frac{\partial c}{\partial F} \cdot dF \qquad (5.2)$$

where $\dfrac{\partial c}{\partial F} = \dfrac{\partial c}{\partial v} \cdot \dfrac{\partial v}{\partial F}$

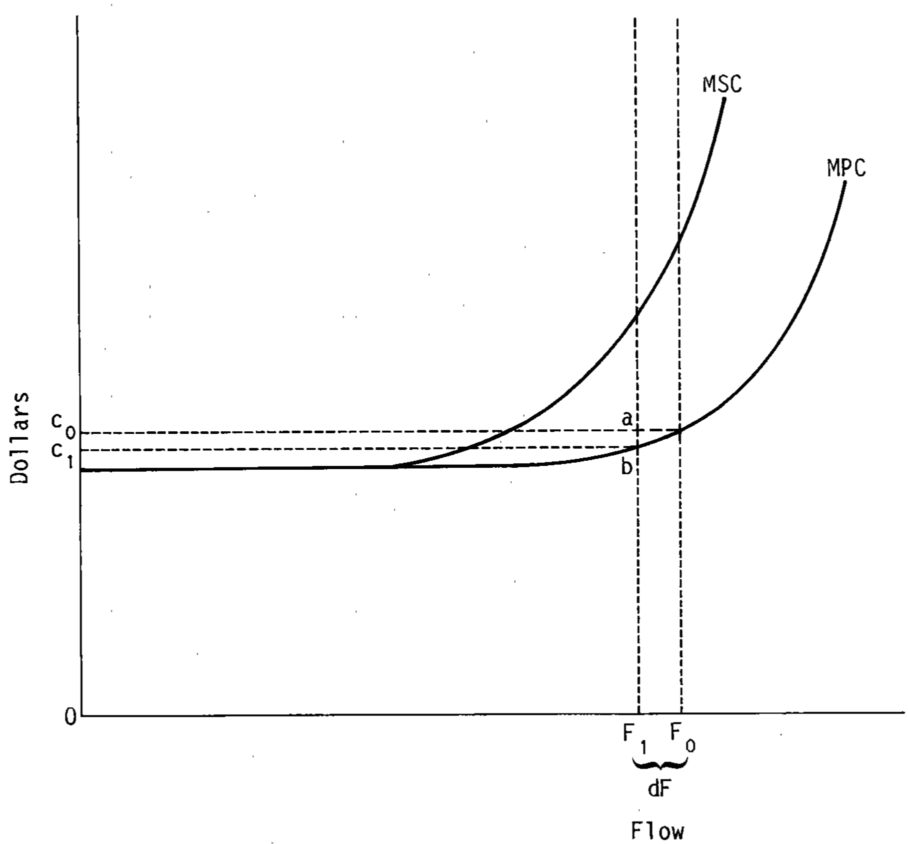

Figure 5.1-Benefits of a reduction in highway congestion

The first component, $\partial c/\partial v$, can be derived from operating cost formulae. The version used in the present study takes the form

$$c = a + {}^{b}/_{v} \tag{5.3}$$

where c = generalised cost per vehicle per km, in cents;
v = speed, in km/hr; and
a and b are parameters. The value of travel time enters the formula via the parameter b.

(This form of operating cost formula is appropriate when dealing with congested conditions. At higher speeds a quadratic term related to speed would also be required.)

Hence,

$$^{\partial c}/_{\partial v} = {}^{-b}/_{v^2} \tag{5.4}$$

The derivative $^{\partial v}/_{\partial F}$ can be derived from speed/flow relationships. The Davidson model is used (Davidson 1966, 1978). It takes the form

$$v = v_f \cdot \frac{K - F}{K - MF} \tag{5.5}$$

where v_f = free flow speed;
K = lane capacity, in vehicle flow per lane per hour;
F = actual vehicle flow per lane per hour; and
M = a variable reflecting the quality of traffic conditions on the road.

If actual speed data are available for the road in question M can be calibrated, since from Equation 5.5

$$M = \frac{K - \frac{v_f}{v} . (K-F)}{F} \tag{5.6}$$

From differentiation of (5.5),

$$\frac{\partial v}{\partial F} = v_f \cdot \frac{K(M-1)}{(K-MF)^2} \tag{5.7}$$

Now combining Equations 5.1, 5.2, 5.4 and 5.7, it is possible to derive the hourly benefit of congestion reduction along a one kilometre lane of road as

$$dc.F = \frac{\partial c}{\partial F} . dF . F$$

$$= \frac{\partial c}{\partial V} . \frac{\partial v}{\partial F} . F^2 . \varepsilon_{fx} . \frac{df}{f}$$

$$= - \frac{b}{v^2} . v_f . \frac{K(M-1)}{(K-MF)^2} . F^2 . \varepsilon_{fx} . \frac{df}{f} \qquad (5.8)$$

By substituting for v from Equation (5.5), this can also be shown to equal

$$dc.F = \frac{- bK (M-1)}{v_f(K-F^2)} . F^2 . \varepsilon_{fx} . \frac{df}{f} \qquad (5.9)$$

To summarise, information is required on:

(i) b - the parameter of the operating cost equation, which equals the value of travel time, in cents per hour, plus that component of vehicle operating costs which is speed-related;

(ii) K - capacity of the highway lane;

(iii) F - actual traffic flow on the lane;

(iv) v_f- free-flow speed on the road;

(v) v - actual speed, which is required to calculate the value of M;

(vi) ε_{fx}- the cross-elasticity of demand between public transport fare and private vehicle trips; and

(vii) $^{df}/_{f}$- the proportional change in public transport fare.

If public transport subsidies were used to improve service levels instead of to reduce fare levels, the appropriate measure of benefits per hour per kilometre of road lane would be:

$$dc.F = \frac{-b}{V^2} . v_f . \frac{K(M-1)}{(K-MF)^2} . F^2 . \varepsilon_{sx} . \frac{ds}{s} \qquad (5.10)$$

where $\varepsilon_{SX} = \frac{dF}{ds} \cdot \frac{s}{F}$ = the cross-elasticity of demand between public transport service level and private vehicle trips,

i.e. $\frac{\text{proportional change in private vehicle trips}}{\text{proportional change in public transport service level}}$; and

$^{ds}/_{s}$ = proportional change in public transport service level.

In the cases of both Equation 5.9 and 5.10 total annual benefits can be derived by summing for the total number of lanes of road in the system, and the total number of hours in the year for which these benefits accrue.

MEASUREMENT OF CONGESTION BENEFITS

The methods used to calculate the benefits of reducing peak-hour congestion in Australian cities are now considered. The main data source is the National Association of Australian State Road Authorities (NAASRA) study of Australian roads carried out between 1980 and 1984 (NAASRA 1984a). This study provides detailed information on arterial roads in Australian cities.

Impact of changes in traffic speeds on operating and time costs

Vehicle operating cost formulae from the NAASRA study (NAASRA 1984c, p.83), updated to 1982-83 prices, are shown in Table 5.1. These formulae show operating costs, *excluding* time costs, for car, van, rigid truck and articulated truck. An overall operating cost formulae for each city was derived by weighting the parameters in the equations in Table 5.1 by weights reflecting the proportions which each of these

TABLE 5.1-VEHICLE OPERATING COSTS, 1982-83 PRICES

(Cents per kilometre)

Vehicle cost	*Cost Formula*
Car	c_a = 6.79 + 119.07/v
Van	c_v = 10.61 + 273.00/v
Rigid truck	c_r = 14.40 + 631.53/v
Articulated truck	c_t = 18.65 + 830.19/v

Note: c = cost per kilometre, and
v = speed in kilometres/hour.

Source: NAASRA (1984c).

types of vehicle represented of the total traffic flow on the road networks of each of the cities, as measured in the Australian Bureau of Statistics' *Survey of Motor Vehicle Usage: Twelve Months ended 30 September 1982* (Australian Bureau of Statistics 1983b). The resulting city-specific parameters are shown in Table 5.2.

Travel time was valued by reference to average hourly earnings in 1982-83 as indicated in Chapter 3. Table 3.2 shows the time values used in cents per hour. These values are per occupant, and so need to be further adjusted by vehicle occupancy rates to yield values per vehicle. These occupancy rates were derived for each capital city from the 1982 Survey of Motor Vehicle Usage (Australian Bureau of Statistics 1983a). The resulting average time values per vehicle for each city shown in Table 5.3 are combined with the operating cost

TABLE 5.2-AVERAGE VEHICLE OPERATING COSTS, EXCLUDING TIME COSTS
(Cents per kilometre)

City	*Cost Formula*
Sydney	$c_s = 7.83 + 177.55/v$
Melbourne	$c_m = 7.63 + 165.71/v$
Brisbane	$c_b = 7.69 + 166.09/v$
Adelaide	$c_a = 7.52 + 159.24/v$
Perth	$c_p = 7.86 + 176.51/v$
Hobart	$c_h = 7.75 + 168.32/v$
Canberra	$c_c = 7.44 + 151.34/v$

Sources: NAASRA (1984c). ABS (1983b).

TABLE 5.3-AVERAGE TIME VALUE PER VEHICLE, 1982-83 PRICES
(Dollars per hour)

City	*Car*	*Truck*	*Average vehicle*
Sydney	4.41	10.80	4.92
Melbourne	4.22	10.03	4.57
Brisbane	4.33	10.03	4.62
Adelaide	4.08	10.29	4.39
Perth	4.07	9.95	4.48
Hobart	4.51	10.54	4.81
Canberra	4.29	11.22	4.50

parameters from Table 5.2 in Table 5.4. This yields estimates of the parameters required to calculate Equation (5.10).

Impact of changes in traffic flow on traffic speed

The NAASRA Australian Roads Study (NAASRA 1984a, b) divides urban arterial roads into categories related to the level of peak period congestion. These categories are defined as 'poor', 'fair' and 'good'. Table 5.5 shows the proportions of road length and travel in different cities which experience these different qualities of congestion in terms of peak period mid-block traffic flow. The assessments were based on data from 1981 inventories of highway characteristics in the various urban areas. The study notes (NAASRA 1984b, p. 45) that the criteria of 'poor', 'fair' and 'good' peak mid-block flows correspond broadly with volume/capacity ratios of over

TABLE 5.4-AVERAGE VEHICLE OPERATING COSTS, INCLUDING TIME COSTS, 1982-83 PRICES

(Cents per kilometre)

City	*Cost formula*
Sydney	$c_s = 7.83 + 670/v$
Melbourne	$c_m = 7.63 + 622/v$
Brisbane	$c_b = 7.69 + 628/v$
Adelaide	$c_a = 7.52 + 598/v$
Perth	$c_p = 7.86 + 625/v$
Hobart	$c_h = 7.75 + 649/v$
Canberra	$c_c = 7.44 + 601/v$

TABLE 5.5-PROPORTIONS OF URBAN ARTERIAL ROAD LENGTH AND TRAVEL EXPERIENCING DIFFERENT LEVELS OF TRAFFIC CONGESTION IN EACH CITY (PEAK MID-BLOCK TRAFFIC FLOW)

	Road length			*Travel*		
City	*Poor*	*Fair*	*Good*	*Poor*	*Fair*	*Good*
Sydney	0.20	0.19	0.61	0.34	0.25	0.41
Melbourne	0.11	0.11	0.78	0.17	0.14	0.69
Brisbane	0.11	0.17	0.72	0.18	0.24	0.58
Adelaide	0.03	0.08	0.89	0.05	0.14	0.81
Perth	0.07	0.08	0.85	0.17	0.12	0.71

Source: NAASRA (1984a, p. 126).

0.9, 0.7 to 0.9, and under 0.7 respectively. Values of volume/capacity ratios were derived from traffic assignments. In the present analysis a maximum volume/capacity ratio value for 'poor' roads of 0.9 was assumed in order to allow for difficulties experienced by the Davidson speed-flow model in dealing with traffic flows too close to theoretical capacity levels. These difficulties arise because the mathematical form of the model implies that speeds tend to zero, and travel times to infinity, as theoretical capacity levels are reached. In practice however, traffic flows can exceed the theoretical capacity levels.

Lane capacity values (K) and free flow speeds (V_f) for each category of road in each city were derived from the lane capacity and free flow speed values adopted by the different States for their assignment modelling. These values are outlined in the NAASRA technical report on urban transport planning techniques (NAASRA 1984c, pp. 43-79). It should be noted that quite large variations exist among the cities in the capacity values adopted for each type of road. Lane capacity and free flow speed values for freeways, divided roads and undivided roads in each State capital were weighted by the proportions which these different types of road represented of the 'poor', 'fair' and 'good' categories of road in each of the cities considered (NAASRA 1984b, pp. 442-448). This yielded average lane capacity (K) and average free flow speed (V_f) for 'poor', 'fair' and 'good' category roads in each city. Actual traffic flow figures (F) could then be derived from the resulting hourly capacity values (K) by multiplying by the volume/capacity ratio for that type of road.

The remaining variable to be estimated was the parameter M in the speed-flow relationship. Some information, reproduced in Table 5.6, was available on actual peak traffic speeds in Sydney, Melbourne and Adelaide (NAASRA 1984d). On the basis of this information and an assessment of how actual traffic speeds vary between 'poor', 'fair' and 'good' category roads an average speed of 25 kilometres per hour was assumed for the 'poor' category of road, 35 kilometres per hour for the 'fair' category, and a value halfway between the free-flow speed, v_f, and 40 kilometres per hour for the 'good' category.

Equation 5.6 was then used to calculate values of M. The resulting values for the different cities and types of road only varied between 0.82 and 0.90, and so an overall value of 0.88 was taken for all roads and cities as best reflecting the influence of road quality on traffic flow. It should be noted that though this value is high in relation to values sometimes used in the Davidson model, the analysis used the model on a system of roads rather than an individual link. M values are therefore likely to be lower where vehicles are unable to seek alternative routes to avoid individual sources of delay.

The impact of changes in traffic flow on speed, $\partial v/\partial F$, were then estimated from Equation 5.7. These figures were then combined with estimates of the change in average operating and time costs as a result of the resulting change in flow, $\partial c/\partial v$, derived from the operating cost formulae discussed in the previous section using Equation 5.4, to yield estimates of the impact of a change in flow on generalised cost, $\partial c/\partial F$. Multiplying by the actual flow, F, the impact of a one unit change in the traffic flow on total generalised costs incurred by all vehicles on a one kilometre stretch of road of a particular type in the peak period in each city was calculated.

Average city-wide values of all these variables were then calculated by weighting, using the proportions of total peak period traffic on each type of road.

Results are shown in Tables 5.7 to 5.10. The tables show that on average a reduction in road traffic by one vehicle-kilometre would reduce the generalised costs of all other highway users by 59 cents in Sydney, 27 cents in Melbourne, 34 cents in Brisbane and 11 cents in Adelaide. These figures are therefore external benefits of the

TABLE 5.6-MEASURED PEAK TRAVEL SPEEDS[a]

(kilometres per hour)

	Central	*Inner*	*Middle*	*Outer*	*Study area*
a.m. peak speeds					
Sydney	28.8	36.3	41.2	58.8	41.1
Melbourne	29.9	38.6	44.7	54.3	42.3
Adelaide	34.0	..	43.0	62.0	47.0
p.m. peak speeds					
Sydney	44.5	42.0	47.3	63.7	48.4
Melbourne	35.5	40.8	41.4	50.0	41.9
Adelaide	36.0	..	44.0	60.0	48.0

a. Travel speeds are weighted by distance travelled.
.. not applicable

Source: NAASRA 1984d, p. 11. Surveys were carried out in November 1981 in Sydney, September/November 1983 in Melbourne, and mid-1983 in Adelaide.

TABLE 5.7-ROAD CONGESTION CHARACTERISTICS; SYDNEY

Peak period congestion conditions	*Proportion of travel on road of each type (W)*	*Volume/ capacity ratio (F/K)*	*Hourly lane capacity (K)*	*Hourly vehicle flow (F)*	*Free flow speed (v_f)*	*Speed/ flow formula parameter (M)*	*Impact of a one unit change in flow on speed ($\partial v/\partial F$)*	*Impact of a one unit change in speed on unit cost ($\partial c/\partial v$)*	*Impact of a one unit change in flow on total cost ($\partial c/\partial F.\ F$)*
Poor	0.34	0.90	822	740	48.5	0.88	0.164	1.232	1.49
Fair	0.25	0.80	825	660	51.0	0.88	0.085	0.565	0.32
Good	0.41	0.42	819	344	50.7	0.88	0.019	0.308	0.02
Average		0.68	822	558	50.0	0.88	0.085	0.686	0.59

TABLE 5.8-ROAD CONGESTION CHARACTERISTICS; MELBOURNE

Peak period congestion conditions	*Proportion of travel on road of each type (W)*	*Volume/ capacity ratio (F/K)*	*Hourly lane capacity (K)*	*Hourly vehicle flow (F)*	*Free flow speed (v_f)*	*Speed/ flow formula parameter (M)*	*Impact of a one unit change in flow on speed ($\partial v/\partial F$)*	*Impact of a one unit change in speed on unit cost ($\partial c/\partial v$)*	*Impact of a one unit change in flow on total cost ($\partial c/\partial F.F$)*
Poor	0.17	0.90	990	891	53.4	0.88	0.150	0.945	1.26
Fair	0.14	0.80	935	748	53.9	0.88	0.079	0.469	0.28
Good	0.69	0.50	977	489	56.3	0.88	0.022	0.246	0.03
Average		0.61	973	594	55.5	0.88	0.052	0.396	0.27

TABLE 5.9-ROAD CONGESTION CHARACTERISTICS; BRISBANE

Peak period congestion conditions	Proportion of travel on road of each type (W)	Volume/ capacity ratio (F/K)	Hourly lane capacity (K)	Hourly vehicle flow (F)	Free flow speed (v_f)	Speed/ flow formula parameter (M)	Impact of a one unit change in flow on speed ($\partial v/\partial F$)	Impact of a one unit change in speed on unit cost ($\partial c/\partial v$)	Impact of a one unit change in flow on total cost ($\partial c/\partial F.F$)
Poor	0.18	0.90	1 261	1 135	48.7	0.88	0.107	1.147	1.39
Fair	0.24	0.80	1 279	1 023	49.7	0.88	0.053	0.556	0.31
Good	0.58	0.45	1 262	568	58.9	0.88	0.013	0.316	0.02
Average		0.62	1 266	779	49.1	0.88	0.040	0.523	0.34

TABLE 5.10-ROAD CONGESTION CHARACTERISTICS; ADELAIDE

Peak period congestion conditions	Proportion of travel on road of each type (W)	Volume/ capacity ratio (F/K)	Hourly lane capacity (K)	Hourly vehicle flow (F)	Free flow speed (v_f)	Speed/ flow formula parameter (M)	Impact of a one unit change in flow on speed ($\partial v/\partial F$)	Impact of a one unit change in speed on unit cost ($\partial c/\partial v$)	Impact of a one unit change in flow on total cost ($\partial c/\partial F.F$)
Poor	0.05	0.90	1 060	954	50.0	0.88	0.131	1.036	1.29
Fair	0.14	0.78	1 186	925	54.7	0.88	0.056	0.406	0.21
Good	0.81	0.45	1 157	521	54.0	0.88	0.015	0.248	0.02
Average		0.52	1 156	599	53.9	0.88	0.027	0.310	0.11

reduction in road traffic. Although they must be treated with some caution because of the sensitivity of the Davidson model to changes in traffic flow close to capacity levels and because of inevitable problems with the underlying data, it is hoped that these results do give an order of magnitude of peak-hour congestion costs on different types of road in different cities.

CROSS-ELASTICITIES OF DEMAND

Having provided estimates of the cost saving resulting from the removal of one vehicle-kilometre from the traffic flow in the four cities considered, the crucial question was how effective public transport policies were likely to be in securing such reductions in highway traffic. It was therefore necessary to know the values of the cross-elasticities between public transport fare level and highway traffic (ε_{fx}), and public transport service level, in terms of kilometres run, and highway traffic (ε_{sx}). In addition, in the case of bus service increases, it was necessary to take account of the fact that an increase in bus-kilometres would *add* to highway congestion, and this increase might lead either to a net increase or decline in traffic depending on whether or not the increase in bus-kilometres was outweighed by the reduction in highway traffic caused by transfer of car users to public transport.

Unfortunately, while there is some consensus that the sizes of the relevant cross-elasticities are likely to be low, there is very little precise evidence on their actual value. Hensher and Bullock's study (1979) of commuter mode choice in Sydney, following a 20 per cent fare cut, estimated a cross-fare elasticity value for non-rail travel of 0.09 for commuters working in North Sydney, but some of the people transferring to rail because of the rail fare reduction would have transferred from bus rather than car. In addition the values of cross-elasticities for CBD workers in cities with good radial public transport networks are in any case likely to be higher than the city-wide cross-elasticity values required for this analysis.

Cross-elasticity estimates have been made for London, England, by Lewis (1977, 1978) using monthly time-series data. Earlier estimates were revised because of a fault discovered in the original computer program used. The revised figures[1] show a peak period cross-elasticity with respect to public transport fares of 0.084 and an all day weekday

1. It is the unrevised figures which are quoted in *Transport and Road Research Laboratory* (1980, p. 121).

cross-elasticity of 0.051. The equivalent service cross-elasticities were -0.108 for the peak and -0.062 for the all-day weekday periods. The full-week fare and service elasticities were +0.080 and -0.060 respectively (Lewis 1978, p. 101). These results were consistent with the earlier suggestions that peak cross-elasticities may be greater than off-peak, and that weekday road traffic may be proportionately more sensitive to service level changes than to fare changes (Lewis 1977, p. 163).

An alternative way of deriving the required cross-elasticities is to consider their relationship with the own-price or own-service elasticities. For example, if a public transport mode has an own-fare elasticity of -0.30, a 10 per cent reduction in fare will lead to a 3 per cent increase in patronage. Some of this increase will come about through diversion from private cars, and this part of the increase can be related to the original level of private car traffic. It can be shown that the own-price and cross-price elasticities are related to each other both via this proportion and via the relative levels of users (or modal shares) of the two methods of transport. Thus for fare cross-elasticities:

$$\varepsilon_{fx} = -\varepsilon_f \cdot \partial_f \cdot (m_{pt}/m_a) \qquad (5.11)$$

where ε_{fx} = cross-elasticity of demand between public transport fare and private vehicle trips

ε_f = ordinary fare elasticity of demand for the public transport mode

∂_f = proportion of increase in public transport trips as a result of a fare change that are diverted from private transport

m_{pt} = modal share for the public transport mode

m_a = modal share for the private transport (automobile) mode.

Similarly for service cross-elasticities:

$$\varepsilon_{sx} = -\varepsilon_s \cdot \partial_s \cdot (m_{pt}/m_a) \qquad (5.12)$$

where ε_{sx} = cross-elasticity of demand between public transport service level and private vehicle trips

ε_s = ordinary service level elasticity for public transport mode

∂_s = proportion of increase in public transport trips as a result of a service level change that are diverted from private transport.

Tables 5.11 and 5.12 show cross-elasticity values using these formulae. Own-fare elasticities were taken from Table 3.1, and own-service elasticities from Table 4.3 (bus) and Table 4.5 (rail). Modal shares were derived from estimates of total passenger-kilometres in each city that were used in the computer modelling discussed in Chapter 6. There was no direct evidence of the diversion share parameters ∂_f and ∂_s, though obviously they must lie between 0 and 1. It was expected that they would be relatively small, since generally, increases in public transport trips are more likely to arise through

TABLE 5.11-FARE CROSS-ELASTICITIES

	$\partial_f = 0.20$			$\partial_f = 0.40$		
	Bus	*Rail*	*All public transport*	*Bus*	*Rail*	*All public transport*
Sydney	0.0048	0.0079	0.0128	0.0095	0.0159	0.0255
Melbourne	0.0025	0.0026	0.0051	0.0050	0.0052	0.0102
Brisbane	0.0027	0.0027	0.0053	0.0054	0.0054	0.0107
Adelaide	0.0037	0.0015	0.0052	0.0074	0.0031	0.0104
Perth	0.0028	0.0006	0.0034	0.0056	0.0012	0.0068
Hobart	0.0032	..	0.0032	0.0065	..	0.0065
Canberra	0.0028	..	0.0028	0.0056	..	0.0056

.. not applicable

TABLE 5.12-SERVICE CROSS-ELASTICITIES

	$\partial_s = 0.20$			$\partial_s = 0.40$		
	Bus	*Rail*	*All public transport*	*Bus*	*Rail*	*All public transport*
Sydney	-0.0065	-0.0166	-0.0232	-0.0130	-0.0332	-0.0462
Melbourne	-0.0033	-0.0061	-0.0093	-0.0066	-0.0122	-0.0187
Brisbane	-0.0041	-0.0068	-0.0109	-0.0082	-0.0136	-0.0218
Adelaide	-0.0060	-0.0026	-0.0086	-0.0120	-0.0052	-0.0173
Perth	-0.0056	-0.0008	-0.0064	-0.0112	-0.0016	-0.0128
Hobart	-0.0061	..	-0.0061	-0.0123	..	-0.0123
Canberra	-0.0056	..	-0.0056	-0.0112	..	-0.0112

.. not applicable

generation of new trips than through diversion from private transport. As a result it was necessary to consider two alternative values of both in Tables 5.11 and 5.12, namely 0.2 and 0.4.

THE CONGESTION REDUCTION BENEFITS OF FARE AND SERVICE CHANGES

The possible levels of congestion benefits from public transport fare reductions or service improvements in Australia can now be considered. This is done by considering the benefits of a 10 per cent fare reduction or a 10 per cent increase in service levels in the different cities. To avoid difficulties of switching *between* public transport modes it was assumed that all public transport fares, or all service levels, were changed by the same proportions.

Fare changes

The figures in Table 5.7 show the benefits of reducing traffic in each city by one vehicle-kilometre. If public transport fares were reduced by 10 per cent, then the vehicle-flow would fall by ($10.\varepsilon_{fx}$) per cent, and the absolute fall in the vehicle flow would simply be equal to this percentage of the total flow. For illustrative purposes it was assumed that there were two peak hours per day in each city, and so it was necessary to calculate benefits in these peak hours only. Thus the reduction in congestion cost was calculated by multiplying the absolute decline in peak-hour traffic, measured in vehicle-kilometres, by the cost reduction per vehicle-kilometre removed from the network. Table 5.13 shows the results of these calculations. This shows the absolute level of (peak-hour) benefits per year and the congestion-reducing benefits per $1 of extra subsidy. The extra subsidy was calculated as equal to the revenue lost throughout the day as a result of the fare reduction and hence is a *minimum* estimate since it ignored any possible cost increases. The benefits ignore any reduction in congestion in the shoulder of the peak, although as the figures in the last column of Tables 5.7 to 5.10 show, congestion cost calculations were dominated by conditions in the most heavily congested situations. These benefits per $1 of subsidy may be *added* to the benefits to users of public transport services as a result of fare changes shown in Chapter 3.

Service level changes

Table 5.14 shows the congestion benefits or costs of service level changes. A 10 per cent increase in bus service levels would lead to an increase in highway traffic calculated by adopting a PCU value of 3.0 for a bus (Lay 1981, p. 189). The reductions in private vehicle

TABLE 5.13-CONGESTION REDUCTION BENEFITS OF FARE CHANGES

			$\partial_f = 0.20$			$\partial_f = 0.40$	
	Peak vehicle kilometres per annum (million)	*Impact of a one unit change in flow-on costs ($)*	*Total benefits ($m)*	*Loss of revenue*[a] *($m)*	*Marginal benefit per $ ($)*	*Total benefits ($m)*	*Marginal benefit per $ ($)*
Sydney	2 267	0.59	1.71	15.00	0.11	3.42	0.23
Melbourne	2 374	0.27	0.32	10.77	0.03	0.64	0.06
Brisbane	863	0.34	0.16	2.30	0.07	0.32	0.14
Adelaide	836	0.11	0.05	1.50	0.03	0.10	0.07

a. Includes losses of revenue from private bus operations, which have had to be estimated. This particularly affects the Sydney figure but does not have a major impact on the size of the marginal benefit per dollar of subsidy.

TABLE 5.14-CONGESTION REDUCTION BENEFITS OF SERVICE LEVEL CHANGES

	$\partial_s = 0.20$			$\partial_s = 0.40$		
	Benefit of reduced auto. traffic ($m)	*Cost of increased bus traffic[a] ($m)*	*Marginal benefit per $ ($)*	*Benefit of reduced auto.traffic ($m)*	*Cost of increased bus traffic[a] ($m)*	*Marginal benefit per $ ($)*
Sydney	3.10	3.96	-0.02	6.20	3.96	+0.05
Melbourne	0.60	1.20	-0.02	1.20	1.20	0
Brisbane	0.32	0.57	-0.03	0.64	0.57	+0.01
Adelaide	0.08	0.26	-0.02	0.16	0.26	+0.01

a. Includes tram traffic in Melbourne.

traffic have been calculated using service cross-elasticity values from Table 5.9. The required increases in subsidy have been calculated by assuming that 80 per cent of bus costs are variable with bus-kilometres and that 50 per cent of rail costs are variable with train-kilometres. It can be seen from Table 5.14 that if only 20 per cent of the new public transport users attracted by the service improvement are attracted from private cars (ie $\partial_s = 0.20$), then congestion will get worse rather than better. If 40 per cent of new public transport users are attracted from cars then traffic conditions will improve in all cities except Melbourne, but the marginal congestion reduction benefits per dollar of extra subsidy are extremely low. This suggests that general public transport service level improvements in the form of increased frequency should not be considered as a way to reduce road congestion in Australian cities[1], and confirms the conclusions of Chapter 4 that there is a strong argument for looking at the case for service level reductions rather than increases.

1. This conclusion may not hold for increases in rail frequency. Extra train-kilometres will not themselves add to road traffic congestion (except at road/rail grade crossings).

CHAPTER 6-A COMPUTER MODEL FOR EVALUATING URBAN PUBLIC TRANSPORT SUBSIDIES

This chapter considers the results of running the computer model developed by the United Kingdom Department of Transport to evaluate the benefits of public transport subsidies. The model was run with 1982-83 data for the seven cities of Sydney, Melbourne, Brisbane, Adelaide, Perth, Hobart and Canberra.

DESCRIPTION OF THE MODEL

The United Kingdom model, known as METS (Model for Evaluating Transport Subsidies), was developed by S. Glaister and the Department of Transport. Full details of the model are provided in United Kingdom, Department of Transport (1982). The model evaluates the benefits throughout a city of changes in public transport policy variables. These policy variables consist of bus fare, bus vehicle-kilometres, rail fare, rail train-kilometres, underground fare, and underground train-kilometres. The latter two variables are relevant only in London.

Demand for each mode is based on a form of demand function which holds fare elasticity proportional to fare level. Own-fare and cross-fare elasticities for the particular city under investigation are inputs to the model. Demand depends on generalised costs, which depend both on money and on time costs. Travel time (i.e. in-vehicle time) depends on speeds. For highway modes (car and bus) speed is derived from traffic flows via speed-flow formulae for different types of road which are inputs to the model. In addition bus speed depends on boarding times and the number of passengers boarding. Rail speed is invariant to flow and is another input. Changes in waiting times for public transport users depend on changes in vehicle-kilometres (via headway) and, in addition, for buses, on load factor (since with high load factors prospective passengers may not be able to board the first bus which appears). Car and truck costs are measured by operating cost formulae which relate cost per kilometre to speed, which is in turn determined by the speed-flow relationships. The model also incorporates public transport operating cost formulae, which in the case of buses allow for the impact of changes in traffic flow on bus operating costs and for the impact of changes in the numbers of bus passengers on boarding times.

Data on base situation traffic flows, service levels and fare levels are inputs. The policy variables can then be changed and the model predicts the impact on traffic flows, speeds, private and public vehicle operating costs, journey times, public transport revenues, producers' surpluses (i.e. profits or losses), and consumers' surpluses. The model computes the net social benefit of the specified policy changes and the net social benefit per £ or $1 of extra subsidy. Given the new equilibrium position the model also calculates the marginal net social benefit of an extra £ or $1 of subsidy spent either on further subsidising fare level reductions or on further subsidising additional vehicle-kilometres. If the latter two values are not equal this implies that the subsidy should be switched from fares to service levels (or vice versa) until they are equal; this will ensure that the maximum net benefits are achieved from a given total level of subsidy. In addition, the model can be used to determine the impact on marginal net benefits of an increase in the total level of public transport subsidy provided for the city under consideration.

DATA

This section outlines the data required for the model, and the sources used. All data relate to the year 1982-83.

Public transport

Vehicle (bus, tram or train) kilometres
Derived from published information or information supplied by operators. A rough estimate had to be made of private bus vehicle-kilometres in Sydney.

Passenger-kilometres
This is not normally measured in Australia, but was calculated by multiplying total journeys by the assumed average journey length for each mode in each city. A rough estimate had to be made of private bus journeys in Sydney.

Average fare per passenger-kilometre
Fare revenue (excluding concessionary reimbursements) divided by total passenger-kilometres.

Fare elasticities
Values from Table 3.1.

Cross-fare elasticities
Values derived from Table 5.8. It was assumed that 30 per cent of new public transport users would be diverted from private cars (ie a_f = 0.30).

Average waiting time
Derived from Equation 4.6 using headway figures in Tables 4.3 and 4.5.

Average boarding time (bus/tram)
See discussion in Chapter 3.

Bus capacity
Average crush capacity of bus and tram fleets calculated from information from operators.

Average rail speed
Estimated from public timetables or information from operators.

Bus and rail total costs
Derived from published information. A rough allowance had to be made for private bus costs in Sydney, Melbourne and Brisbane.

Private transport

Car and truck vehicle-kilometres
Totals derived from data in the NAASRA (1984b) study, and car/truck split calculated from vehicle split in Australian Bureau of Statistics (1983b). Vehicle-kilometres in the NAASRA study relate to the year 1981, but have not been revised because of the inevitable difficulties in measuring city-wide traffic levels accurately.

Car and truck passenger-kilometres
Derived by multiplying vehicle-kilometres by average occupancy rates for each city taken from Australian Bureau of Statistics (1983b).

Passenger car units
Assumed to be equal to 1.0 for cars, 2.0 for trucks and 3.0 for buses as suggested by Lay (1981, p. 189).

Highways

Type of highway
Four types of highway were distinguished:

(i) freeways

(ii) divided roads

(iii) major arterial undivided

(iv) minor arterial undivided.

These conform to the following road stereotypes in the NAASRA study: (i), 3; (ii), 2(a) to 2(d); (iii), 1(b) to 1(d); and (iv), 1(a). Lengths of each type of road and the proportions of traffic on each road are available in NAASRA (1984b, pp. 442-8).

Speed/flow curve parameters
The model uses linear speed-flow curves. The parameters for them were derived from the (non-linear) speed-flow curves and from the free-flow speeds for different cities published in NAASRA (1984c, pp. 43-53).

Vehicle operating costs
The operating cost formulae parameters for cars and trucks in Table 5.1 were used after adjusting for proportions of cars and vans, and rigid and articulated trucks, in each city taken from Australian Bureau of Statistics (1983b).

Value of time
In-vehicle values of travel time by mode and city from Chapter 3.

RESULTS

The model was run for each of the seven capital cities to assess the benefits of a reduction in public transport fares and the benefits of an increase in service levels. Results are presented in terms of the average gross benefit per extra $1 of subsidy of reducing fares by 1 per cent, or increasing vehicle-kilometres by 1 per cent. These percentage changes in policy variables are small, and the resulting average values are very close to the marginal values; therefore the average values are not reproduced. An average benefit value in excess of $1 indicates that the policy change leads to an increase in net social benefits, a value below $1 indicates a reduction in net social benefits[1].

Results in Table 6.1 are based on the assumption that marginal costs per bus-kilometre were equal to 80 per cent of average costs, while

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1. The program actually computes net social benefits per $1. Gross social benefits equal (1 + net social benefits).

marginal costs per train-kilometre were equal to 50 per cent of rail average costs. This is referred to as the 'low' cost assumption. Table 6.2 shows the results of testing the sensitivity of the overall results to this assumption by permitting bus marginal costs to equal average costs and rail marginal costs to equal 80 per cent of average costs. This was the 'high' cost assumption.

Table 6.1 shows that fare reductions are justified in all cities. Though there were fairly similar levels of benefit per extra $1 subsidy in different cities, differences in benefit were broadly consistent with the relative levels of congestion costs estimated

TABLE 6.1-BENEFITS PER DOLLAR SPENT ON INCREASED PUBLIC TRANSPORT SUBSIDIES, 'LOW' COST ASSUMPTION, 1982-83
(Dollars)

City	*Reducing all public transport fares by 1 per cent*	*Increasing all public transport vehicle-kms by 1 per cent*
Sydney	1.35	0.43
Melbourne	1.28	0.40
Brisbane	1.32	0.87
Adelaide	1.31	0.44
Perth	1.31	0.72
Hobart	1.27	0.75
Canberra	1.26	1.00

TABLE 6.2-BENEFITS PER DOLLAR SPENT ON INCREASED PUBLIC TRANSPORT SUBSIDIES, 'HIGH' COST ASSUMPTION, 1982-83
(Dollars)

City	*Reducing all public transport fares by 1 per cent*	*Increasing all public transport vehicle-kms by 1 per cent*
Sydney	1.34	0.30
Melbourne	1.26	0.27
Brisbane	1.30	0.58
Adelaide	1.29	0.32
Perth	1.29	0.52
Hobart	1.25	0.57
Canberra	1.24	0.76

separately in Chapter 5. Service level increases are not justified except very marginally in Canberra. Apart from Canberra, the case for service improvements was least bad in Brisbane and Perth. The case was much poorer in Adelaide, Sydney and Melbourne.

Results for the higher public transport operating cost assumption shown in Table 6.2 indicate that the benefits of fare reductions are only slightly sensitive to public transport operating costs. This is because, like the simple fare benefits model discussed in Chapter 3, the METS model assumes that most increases in public transport demand can be handled with existing capacity. In contrast, and as was expected, higher operating cost assumptions make the case for service improvements appear worse; the second column of Table 6.2 shows the same relative demerits of service improvements in the different cities as revealed by Table 6.1, with service improvements now not justified in Canberra.

Results have also been tested with regard to their sensitivity to the estimated values of waiting time. Actual waiting time information was available for Melbourne from the unpublished tabulations of the 1978-79 Home Interview Travel Survey (Ministry of Transport Victoria 1981). These revealed an average waiting time for bus and tram services of 4.37 minutes (compared with the predicted value used here of 3.90 minutes) and an average waiting time for rail services of 5.00 minutes (compared with the predicted value used of 5.80 minutes). These actual waiting times were substituted into the model and yielded predicted benefits per extra $1 of an all-round 1 per cent fare cut in Melbourne of $1.27 (compared with the figure of $1.28 in Table 6.1) and, for an all-round 1 per cent service increase, benefits of $0.41 (compared with the figure of $0.40 in Table 6.1).

The benefits of separate fare or service level changes by mode have also been considered in those cities with rail networks, though no allowance has been made for fare cross-elasticity between public transport modes. Results for the 'low' cost assumption are shown in Tables 6.3 and 6.4 and compared with the results of the all-round fare or service changes. The results confirm earlier conclusions in favour of fare cuts and service reductions. With regard to fares, it appears from Table 6.3 that there is a greater case for rail rather than bus fare reductions in all cities except Melbourne, where rail and bus fares appear to be in the right balance with each other. Note that these results partly reflect the excess capacity on rail networks, and that integrated fare structures in Adelaide and Perth might prevent differential fare adjustments being made. With regard to service levels, the results in Table 6.4 suggest a somewhat greater case for bus rather than rail service reductions in Sydney and Adelaide, and in Brisbane (though with regard to this city the case for reducing service levels on either mode is less than in the other cities with rail services). There is a stronger case for rail rather than bus (or tram) services reductions in Melbourne and Perth. Note in particular, however, that these cross-modal comparisons for service level changes will be very sensitive to the particular assumptions that have been about marginal costs for both bus and rail services. The service improvement benefits in Table 6.4 can be compared with the estimates of the direct user benefits of such service (i.e. frequency) improvements shown in the final columns of Tables 4.3 and 4.5, and calculated using the simple model described in Chapter 4. This simpler model, it will be recalled, excludes any allowance for changes in highway congestion.

TABLE 6.3-BENEFITS PER DOLLAR SPENT ON FARE REDUCTIONS, 'LOW' COST ASSUMPTION, 1982-83

(Dollars)

City	*Reducing all fares by 1 per cent*	*Reducing bus fares by 1 per cent*	*Reducing rail fares by 1 per cent*
Sydney	1.35	1.25	1.43
Melbourne	1.28	1.28	1.27
Brisbane	1.32	1.27	1.40
Adelaide	1.31	1.24	1.63
Perth	1.31	1.27	1.60

TABLE 6.4-BENEFITS PER DOLLAR SPENT ON SERVICE IMPROVEMENTS, 'LOW' COST ASSUMPTION, 1982-83

(Dollars)

City	*Increasing all vehicle-kms by 1 per cent*	*Increasing bus-kms by 1 per cent*	*Increasing train-kms by 1 per cent*
Sydney	0.43	0.37	0.52
Melbourne	0.40	0.45	0.34
Brisbane	0.87	0.84	0.90
Adelaide	0.44	0.42	0.50
Perth	0.72	0.81	0.35

COMPARING THE TWO APPROACHES

The study has used two approaches to estimating the benefits of changes in urban public transport subsidies. There are many differences in detail between the two approaches; in particular it should be noted that the METS model is far more complex than the models used in the earlier chapters. However, it must be stressed that both approaches share the same underlying rationale in terms of their use of the cost-benefit analysis framework and the methodologies used to evaluate costs and benefits; differences for the most part are in complexity, rather than in the types of cost or benefit measured or in the data used to measure them.

Nevertheless, two particular differences should be noted. First, in the measurement of congestion costs the approach adopted in Chapter 5 uses the non-linear Davidson speed-flow relationship. This may better reflect the marginal impact of changes in traffic flow on speed when conditions are particularly congested, but the results then become very sensitive to assumptions made about the relationship itself when flows are near to capacity. The METS model uses linear speed-flow relationships which we have had to extrapolate rather crudely from non-linear relationships in the NAASRA study. The METS model on the other hand incorporates a process to determine equilibrium levels of traffic flow when demand changes, whereas in the congestion model of Chapter 5 a reduction in traffic flow as a result of a public transport policy variable change is assumed to have no further impact on traffic flow. (This is equivalent to assuming that the demand curves in Figure 5.1 are vertical). More work is clearly needed on investigating the sensitivity of results to the congestion model used and in trying to combine the best of both approaches. The enormous amount of data collected and collated by the NAASRA study presents an ideal opportunity in this regard.

Secondly, the approaches differ in their treatment of service (i.e. vehicle-kilometre) elasticity. In the model employed in Chapter 4 service elasticity values were fed into the model in order to predict the impact of service increases in generating extra revenue to partially offset the costs of the increases in vehicle-kilometres. In the METS model, however, service elasticity values are not input, but their values are implied through the impact of vehicle-kilometre changes on generalised cost and hence demand. Table 6.5 compares service elasticity values used in Chapter 4 with those implied in our runs of the METS model for different cities. There are some differences, though they should not be expected to have a great impact on the overall results.

TABLE 6.5-COMPARISION OF SERVICE (VEHICLE-KILOMETRE) ELASTICITIES, 1982-83

	Assumed in model of Chapter 4	*Implied in METS model runs*
Sydney		
Bus	0.41	0.35
Rail	0.42	0.12
Melbourne		
Bus/tram	0.40	0.25
Rail	0.47	0.09
Brisbane		
Bus	0.53	0.50
Rail	0.63	0.41
Adelaide		
Bus	0.49	0.46
Rail	0.60	0.59
Perth		
Bus	0.60	0.53
Rail	0.49	0.37
Hobart		
Bus	0.57	0.45
Canberra		
Bus	0.60	0.73

CHAPTER 7-CONCLUDING REMARKS

The object of this Paper was to set out some of the methods that could be used for the assessment of subsidies to urban public transport.

The study was restricted to considering changes to the economic efficiency of urban public transport. It is commonly found both in the technical literature and in the press that benefits and costs (or losses) are discussed in very general terms with little or no justification for the conclusions reached. For example, subsidies or losses are often justified on ex-post grounds with little or no quantitative analysis to support such statements. For example, with regard to public transport subsidies in Australia, it has been suggested that 'it is generally believed that the extra costs associated with road works and road congestion, as well as potentially dramatic alteration of movement and activity patterns, would outweigh the present cost of supporting transit systems' (Commonwealth Grants Commission 1982, p. 72). However, Amos and Starrs' work (1984) on quantifying the benefits of subsidies in Adelaide suggests that this is not so for the one city in Australia where serious quantification has so far been attempted.

Although considerable additional analysis is required in the area of subsidies, this study indicated that there were benefits to be derived from a reduction in the level of public transport services in many of the Australian cities, and a switch of the subsidies saved to finance lower fare levels. Although the results contained in this study are indicative of relative magnitudes and not absolute values, this conclusion was reached for both bus services and rail services. In both cases a reduction in the amount of subsidy spent on service levels could be expected to lead to an increase in benefits.

The present study has not investigated the level of subsidy which would be optimal from an economic efficiency point-of-view. This would first involve achieving the right balance between fare and service levels for a given level of subsidy. This would occur when the marginal benefits per extra $1 of subsidy devoted to fare and service level changes were equal. The resulting value of the marginal benefit per extra $1 of subsidy could then be compared with the marginal cost (or opportunity cost, or shadow price) of the Government funds used to finance the subsidy. The optimal subsidy level (at least in the economic efficiency sense) would be achieved where the marginal benefit per extra $1 of subsidy was equal to this marginal cost.

Interest in the concept of the marginal cost of Government funds was awakened by the important paper by Browning (1976). Economic (i.e. cost-benefit) appraisal of Government current and capital expenditure projects has generally proceeded on the basis that economic efficiency is increased (in the Hicks-Kaldor compensation test sense) if the net benefits of the Government expenditure are positive. However, this ignores the economic efficiency losses which may be incurred elsewhere in the economy through the raising of funds to finance the extra Government spending. Estimates of these marginal excess burdens or deadweight losses per extra $1 of tax revenue have recently been made in the United States by Stuart (1984) and by Wildasin (1984). In Australia Findlay and Jones (1982) presented estimates of the marginal cost of Australian income taxation. Depending on how extra income tax revenue is to be raised, they estimated that the shadow price of a dollar of Government funds raised from this source could vary between $1.23 and $1.65. These figures appear high in relation to estimates for other countries, through they may simply reflect particular features of the Australian tax system.

Although this study has concentrated on economic efficiency issues, there are a number of other factors which have to be considered in order to arrive at an optimal policy for expenditure on public transport. Technical efficiency, income distributions and long-term investments are among the many facets of urban public transport which also have to be considered by the decision maker.

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ABBREVIATIONS

ACTION	Australian Capital Territory Internal Omnibus Network
METS	Model for Evaluating Transport Subsidies
MMTB	Melbourne and Metropolitan Tramways Board
MTA	Metropolitan Transit Authority (Melbourne)
MPTT	Metropolitan (Perth) Passenger Transport Trust
MTT	Metropolitan Transport Trust (Tasmania)
NAASRA	National Association of Australian State Road Authorities
QR	Queensland Railways
SRA	State Rail Authority (New South Wales)
STA	State Transport Authority (South Australia)
TRRL	Transport and Road Research Laboratory
UTA	Urban Transit Authority (New South Wales)