# 25 Managing on-road public transport

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## 1 INTRODUCTION

Cities continue to play a leading global economic and social role. In 2007, for the first time in history, more than half of the worlds' population were city dwellers (United Nations Population Fund 2007). Between 2000 and 2030 the worlds' urban population is expected to double. This is the 'Urban Millennium' where the functioning of cities has a principal influence on human endeavour (United Nations Population Fund 2007). The prospects for the development and operation of transport systems to support growing cities, particularly those in western developed countries such as Australia, is extremely challenging. Travel is dominated by the private car (Cosgrove et al. 2009) which is becoming increasingly problematic from a number of perspectives:

- Traffic congestion is now widely recognized as a major and growing urban transportation problem (Cervero 1991; Downs 1992; Arnott and Small 1994). In Australia congestion costs AU$9.4 billion per annum. (2005) and is expected to rise to AU$20.4 billion by 2020 (Bureau of Transport and Regional Economics 2007).
- There are also social impacts of car traffic on urban liveability (Vuchic 1999) including the separation of urban communities by busy roads and impacts on social disadvantage (Rosenbloom 2007).
- Research has established strong links between physical activity and health (British Medical Association 1997; Dora and Phillips 2000). Public transport use involves more physical activity compared with car travel, suggesting growing health concerns as car use increases (Woodcock et al. 2007).
- Transport, mainly private car travel, is the only sector of the UK economy for which environmental emissions in 2007 are higher than in 1990 (Woodcock et al. 2007). They are also increasing in Australia and remain a major focus of concerns for greenhouse gas and climate change (Bureau of Infrastructure Transport and Regional Economics 2009).
- Motorized transport is over 95 percent dependent on oil and accounts for almost half of world use of oil (Woodcock et al. 2007). There is a growing consensus that oil reserves are falling and that the costs of transport will increase as a result (Dodson and Sipe 2006). These issues suggest significant risks associated with car dependent transport futures.

Improving existing and developing new public transport (PT) systems have been widely seen as part of a global solution to these problems (Vuchic 1981, 1999; Beimborn et al. 1993; Larwin 1999; Bunting 2004). However, there are substantive challenges facing PT, particularly in the developed world context:



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- Most urban public transport in almost all world cities is road based. Even in London, which has one of the largest subway systems in the world, buses carry 76 percent more passengers (ridership) every day than London Underground and Docklands Light Railway combined (2010 figures; Transport for London 2011). In Australian capital cities, road-based public transport (bus and tram) carry 29 percent more annual journeys than urban rail (2010 figures; BITRE 2013). In the USA, bus accounts for over 53 percent of all national ridership (2013 figures; American Public Transportation Association 2014).
- Operating in mixed traffic substantially impairs the operational performance and attractiveness of road-based public transport. As traffic congestion grows performance of road-based public transport further deteriorates.
- Roads and the streets/urban form within which they are placed are designed almost exclusively for car access and parking. Operation of buses and trams in traffic within these roads is not well suited to their effective performance.

In effect road-based public transport is widely seen as a cost-effective solution for the urban transport problem. However, owing to the design of the urban road fabric, and the operational and delay-based impacts of traffic using roads, the benefits of road-based public transport are not being realized. A major solution to this impasse is the improved management of road-based public transport within the road system.

This chapter reviews the current 'state of the art' of approaches to better manage road-based public transport.[1] Its focus is on current approaches to managing buses and trams (or streetcars) which use roads in mixed traffic conditions in developed world contexts where car traffic often dominates travel. The chapter commences with some definitional context to better clarify road conditions and the types of road-based public transport. The problems and issues of road-based public transport are then discussed with management approaches discussed next. The management approaches commence with a review of the types of road-space priority to public transport (for example, bus lanes) and road-time priority (for example, traffic signal priority). Concepts of public transport in road design are then described. The chapter concludes with a discussion of current 'state of the art' applications and prospects for improved management of public transport on roads into the future.

## 2 DEFINITIONS FOR PUBLIC TRANSPORT ON ROADS

Right of way (ROW) provided for urban public transport systems has been usefully divided into three categories (Vuchic 1981), which is of help in understanding the context for managing public transport on roads:

- *Category A, Fully controlled* – without grade crossings or any legal access by other vehicles or pedestrians. Terms used in relation to this are 'exclusive', 'private' or 'segregated'. Includes tunnels, overhead tracks or in exceptions an at grade right of way which is segregated and with signal over-ride at crossing points.
- *Category B, Longitudinally physically separated* – this has physical separation by

curbs, barriers or grade separation from other traffic. However, there are grade crossing points for other vehicles and pedestrians.

- *Category C, Mixed traffic* – where public transport services share the road with other vehicles. However, this can include some allocation of priority to public transport vehicles excluding physical segregation (which would make this a category B ROW).

Right of way C is the major concern for managing road-based public transport; however, ROW B is also relevant at intersections where roads cross longitudinally physically separated alignments of urban public transport.

In developed world contexts, the most common urban public transport mode using roads with ROW C is buses. However, rail-based modes, including trams, also share ROW C contexts. In North America these systems are often termed 'streetcars'. Streetcars once dominated travel in developed world cities in the mid-twentieth century (Currie and Burke 2013). However, the poor operational performance of trams in traffic and the resulting increases in costs have resulted in withdrawal of most of these systems.

Right of way B contexts were, by the late twentieth century, almost exclusively operated by light rail systems. By definition, light rail implies a rail-based car operating in a separated (or segregated right of way) (Vuchic 1981). However, the growth of bus rapid transit systems in the late twentieth century has seen the development of numerous busway alignments in ROW B contexts in numerous cities worldwide (Levinson et al. 2003).

The other major definitional components of urban road-based public transport includes passenger facilities, vehicle storage systems and control systems:

- Passenger facilities are the stops or stations where public transport vehicles alight or board passengers. Passengers must wait at these facilities, so provisions of amenities for shelter, comfort and safety are common. Access to public transport can be multi-modal, hence passenger facilities often cater for short- or longer-term parking of vehicles, bicycle lockers and transfers between public transport modes. Drop-off car access to public transport is often termed 'kiss and ride', while car access involving the longer-term parking of the car at a public transport station is termed 'park and ride'.
- Vehicle storage may be known as depots, or rail yards. Often, large buildings are also required for vehicle maintenance and repair. These are not necessarily located where vehicles are stored.
- Control systems including vehicle detection, communication and signal equipment, and any central control and monitoring facility. Power supply systems are a requirement for electrically powered modes.

## 3 PUBLIC TRANSPORT–ROAD TRAFFIC INTERFACE: ISSUES AND PROBLEMS

There are a wide range of issues and problems associated with the operation of road-based public transport that motivate improved management, including:

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- traffic interference;
- reliability;
- the public transport peak period problem;
- vehicle utilization;
- vehicle access and size;,
- route productivity;
- passenger comfort;
- passenger safety; and
- traffic safety.

**Traffic Interference**

Road-based public transport modes travel at speeds which are well below those of car traffic. Bus services in ROW category C situations typical run at speeds in the 15–20 kilometres per hour (kph) range (including stopping and dwell times) with speeds falling to around 10 kph in busy congested main streets. Trams, light rail and bus can be faster depending on the extent of ROW B conditions on the alignment. Slow operating speeds are a major deterrent to use of road-based public transport. Traffic delays are a major proportion of total delays. However, the need for public transport vehicles to board and alight passengers at stops and terminals is also a cause of delay.

Traffic delays to on-street public transport mainly occur at intersections. Queuing in general traffic is a problem although public transport is also delayed by both right- and left-turning vehicles. Trams, and to an extent trolley buses, are particularly disadvantaged with delays from turning traffic since they have more limited opportunities to bypass turning traffic queues. Delays can also occur when public transport vehicles must merge into traffic streams.

**Reliability**

While slow public transport operating speeds are a major deterrent to use of road-based public transport, unreliable services as a result of traffic delays is the most significant deterrent. An international review of research measuring passenger perceptions of public transport travel time (Booz Allen Hamilton 2000) highlighted how passengers value different elements of the journey:

- travel time in the vehicle – perceived value is 1 actual travel time; and
- unexpected waiting time at the public transport stop (owing mainly to traffic delays) – perceived value of between 4 and 6 times actual travel time.

Hence a minute saved of unexpected waiting time is valued around five times higher than a minute saved within the vehicle.

Unreliable public transport services do much more than deter passengers. This unreliability also acts to systematically break down the ordered provision of public transport services. The headway provided on the route can be a fine balance between the capacity available within vehicles, the size of the public transport fleet and the arrival rates of passengers at public transport stops. When traffic congestion delays a public transport vehicle, it creates a positive feedback loop that acts as follows:

1. Traffic delays make a public transport vehicle run behind schedule.
2. The vehicle is late at arriving at the next stop.
3. More passengers arrive at the stop because there is more time for them to accumulate.
4. When the late vehicle arrives a larger than expected number of passengers board.
5. This delays the vehicle further since boarding time takes longer.
6. Go back to 1.

Hence small delays can become big delays in congested conditions. The result is 'bunching' of public transport vehicles, overloading of public transport vehicles and wastage of public transport capacity. Typically the first vehicle in a delayed series of vehicles is full while the following vehicles are empty. These are expensive resources for the public transport operator to provide for no or little gain. This problem is typically more apparent in the peak period.

**The Public Transport Peak Period Problem**

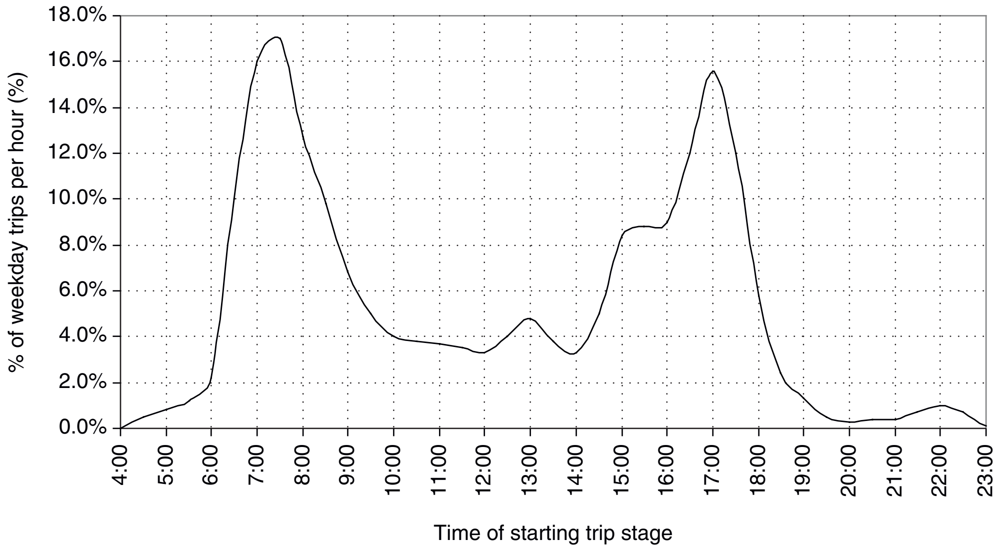
Provision of public transport services is an expensive business with usually little financial return from fares. In Australia and North America, typical cost recovery rates from fares are around the 30–50 percent of costs. Only in extremely high-volume and high-density situations, such as Hong Kong, are services profitable. It is hence a major priority of public transport operators and planners to be vigilant about their costs.

The costs of running road-based public transport systems are primarily centred in their crew and vehicle fleet. Even expenses such as depot or administrative overheads are related to fleet and labour force size. It is therefore an entirely prudent approach for public transport operators to minimize the size of fleet and crew resources required for a given operation.

Unfortunately, the demand for public transport is highly peaked (Figure 25.1).

It is therefore necessary for public transport operators to obtain sufficient vehicle and crew resources such that the peak demand is covered. This is an unfortunate situation since the peak vehicle requirement is substantially above that required for the rest of the day. In effect typically more than 50 percent of the peak fleet and crew requirement is only used during around 5 hours of each 20-hour weekday. This is very inefficient. It is hence a major objective of efficient public transport operators to concentrate their efforts to manage the use of their resources in the peak. They are focused on the effectiveness of the vehicles they deploy in peak periods.

It is another 'unfortunate truth' of road-based public transport management that when efficiency of use of vehicles in the peak is critical to cost-efficiency it is also the time when speeds of buses and trams are slowest owing to traffic congestion. This is one of the great 'tragedies' of road-based public transport planning; interference from traffic is worst when planners need speeds to be the most efficient.




*Source:* Authors graphing of results from Transport Research Centre (1996).

*Figure 25.1 Typical public transport weekday demand profile*

**Vehicle Utilization**

Because of the peak period problem, bus and tram operators are very focused on ensuring efficient vehicle utilization, particularly during the peak. Good utilization means vehicles are running as quickly as possible without undue delay. Reliability is an essential component of good utilization. If delays cause the breakdown of reliable public transport schedules (such as with the positive feedback loop identified earlier) then some vehicles run empty while others are overloaded with passengers.

Effective vehicle utilization can also mean counter-peak direction buses run empty. It is a common strategy of peak bus operation to run vehicles out of service in the counter-peak direction such that they get back to the start of the route as quickly as possible (Kittelson & Associates et al. 2003). This makes it possible to run additional peak direction vehicle trips, which reduces the peak vehicle requirement and can mean that operators request priority for empty buses.

It would be desirable to run larger public transport vehicles in the peak and smaller vehicles in the off peak. With some light rail units, this is achievable if a 'rail set' consisting of several light rail cars can be broken up to a single car for the off peak. For buses this is not possible. This is why large buses are often seen operating in low-demand locations and times of the day. It is also the reason that small buses are difficult to add to bus fleets. A minibus is a difficult vehicle to deploy in the peak owing to the high demands at that time. It would be possible to have a large bus for the peak and a small bus for the off peak, however, two buses would then be required. This doubles the fleet resource needs rather than reducing it (Hemily and King 2002).

**Vehicle Access and Size**

Public transport vehicles can be some of the largest and least manoeuvrable on the road. It is often the nature of route operations that larger high-capacity public transport vehicles must also be the vehicles which are used to penetrate into narrow suburban blocks or inner city lanes. It is important that road widths and traffic control devices (speed humps and roundabouts) are designed so as not to limit the ability for these vehicles to be deployed. There is a trend towards the use of low-floor and longer-route bus vehicles. This can increase the physical access requirements for public transport on roads.

Public transport operators are also concerned about the use of temporary road management measures during road maintenance and repair activities. Notice of lane closures including measures to temporarily realign routes is important. Options are more imposing to address lane closures for tram and light rail services in ROW category C circumstances. Here temporary bus services must be contracted. Implementing these measures requires time and effort. There are has been much concern in the public transport industry that notice of road closures is reducing. Outsourcing of road maintenance activities appears to have exacerbated the communication difficulties associated with notice of temporary road closures in some cases.

**Route Productivity**

While operators are concerned that public transport vehicles should be productively used it follows that the routes they run on are also productive. Route productivity means that the fixed alignment which vehicles follow must have passenger-attracting features along its full length. For this reason route alignments that cross open fields are less effective than those that penetrate into residential areas. Routes that finish in car parks are less effective than services that stop at the front door of major shopping centres. In addition, routes that must operate in cul-de-sacs are not productive. Here the bus route must turn around and cover the length of the cul-de-sac where it has already provided access. In effect it halves its productive capacity. It is better to have route loops that continuously cover new passenger catchments than to run buses along roads they have already covered.

**Passenger Comfort**

The provision of adequate lighting is an important issue for public transport stops. Passengers must wait for buses and trams at night as well as during the day. Weather conditions are also a concern. Adequate lighting, shelter and seating are common requirements for all public transport stops.

The design of public transport vehicles and stops to ensure access of persons with disabilities is a major concern of transport policy internationally. There are concerns that the now mandatory vehicle and public transport stop design requirements in some countries are not being followed up with similar requirements for pathways to and from the public transport system.

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**Passenger Safety**

Passenger safety is the single most important criteria for public transport planning. It includes concerns over personal security, particularly as this affects travellers at night. It is therefore an important factor in traffic engineering for on-road public transport. Public transport planners are concerned to ensure safe passage of passengers to and from stops as well when waiting for public transport services and within public transport vehicles.

Ensuring safe access to and from public transport stops and stations is difficult since it is often the remit of many separate organizations to manage these issues. Traffic engineers are more likely to be involved in this area. It is a common concern, for example, that bus stops are often located on a verge away from pedestrian access paths. Road crossing points should be located near to public transport stops since public transport passengers must always cross the road at least once for every return journey.

A major safety concern whenever transport vehicles interface with people is to ensure the safe separation of the two. At major interchanges traffic engineers are often involved in design layout and planning for access within and to and from these facilities. Good design tries to segregate pedestrian and vehicle movements but compromises are often necessary.

**Traffic Safety**

Road-based public transport vehicles are large, heavy, frequently stopping and relatively slow-moving vehicles operating within traffic flows. Traffic flow 'friction' between parking traffic and road-based public transport vehicles, conflicts between turning traffic and road-based public transport vehicles, and slowing, merging and overtaking movements of traffic to avoid road-based public transport vehicles, all represent risks which can result in road crashes. Recent research on the before/after effects of removing buses from the traffic stream and into bus lanes demonstrated an 18.2 percent reduction in traffic crash rates (Goh et al. 2013). The largest declines in crash type as a result of removing buses from the traffic stream were declines in 'rear end' and traffic-merging accidents as vehicles try to overtake buses. Related research showed that bus-related crashes were also considerably reduced as a result of moving buses into bus lanes; this resulted in a decline of 53 percent in bus accident rates (Goh et al. 2014).

## 4 PUBLIC TRANSPORT PRIORITY

Public transport priority is the adoption of traffic engineering measures to positively discriminate in favour of public transport vehicles, usually on the basis of the greater passenger-carrying abilities of these modes and hence their more efficient use of limited available road space or road time. There are two major kinds of priority; road design measures and traffic signal priority measures. This section describes these kinds of treatment, explores approaches to justifying their implementation and discusses the benefits observed from priority treatments to roads. Some of the practical lessons learned from priority implementation are also discussed.

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### Road Design Measures

Complete (longitudinal) separation of the ROW of a road-based public transport route shifts its ROW category from ROW C to ROW B. Conventionally this involves conversion of tram to light rail or on-street bus to busway. This is the highest form of priority road design measures. However, priority-using road design can also be provided for ROW C contexts without full segregation. Table 25.1 illustrates some of the treatments that can be adopted. In general these measures seek:

- quicker and more reliable flows of public transport vehicles with a focus on passing through intersections; and
- vehicle access pathways through urban development which are more direct or not possible by car.

### Traffic Signal Priority Measures

There is much evidence that, like the rest of traffic, public transport vehicles are delayed because of the problem of passing through signalized intersections. As White (2002, p. 53) puts it: 'Up to a third of bus journey time (especially in peak and/or congested conditions) may be spent stationary – roughly half at passenger stops, and half at traffic-light controlled intersections . . . These are also the periods with the heaviest passenger flows'.

There has been a considerable amount of effort put into designing traffic-light systems to improve public transport operations. Table 25.2 shows some of the key measures that are adopted. There are two key types of traffic signal measures:

- Passive traffic signal priority – these adjust standard traffic signal parameters to ensure the average operations of the light systems favour what is known to be the average operation of public transport. These systems do not 'actively' detect public transport vehicles. Rather, they involve modifying traffic signal operations with expected public transport movements through intersections.
- Active traffic signal priority – where active detection of the vehicle triggers signal phase adjustments which favour public transport. Active detection is also termed selective vehicle detection (SVD). There are essentially three types of these:
  - Detective loop systems – here the inductive loops linked to traffic signal systems are adjusted to detect long vehicles, such as buses. Long loops involving two adjacent inductive loops or a single large loop can be used in this way. Alternatively, it is possible to use microprocessors to detect the standard profile of a public transport vehicle using standard inductive loops
  - Tag-based systems – these include tags which can be electronic or infrared, radio or even radar emitters to act as a beacon on the public transport vehicle. This requires reception technology associated with the traffic-light system
  - Integrated priority systems – which are linked to public transport automated vehicle monitoring (AVM) and automatic vehicle location (AVL) systems which are usually used to manage the day-to-day on-road operations of the public transport system.

*Table 25.1 Typology of public transport priority measures – road design measures*

| Measure | Details |
|---|---|
| Public transport lane – with flow (See Figure 25.2) | ● Separated by line marking, or alternative coloured roads. Can be full-time or peak only. Can be shared with cycle traffic, high occupancy vehicles or even freight<br>● Emergency vehicles usually share the lane when needed<br>● Policing required to ensure rules are adhered to |
| Public transport lane – contra-flow | ● Where public transport lanes operate in the opposite direction to other traffic flows<br>● Defined in two key circumstances:<br>– Within one way street systems – they provide a more direct route through a CBD than the often circuitous paths required in a one way system<br>– Taking advantage of tidal traffic flows and using non-peak direction traffic lanes to operate an additional contra-flow public transport service<br>● Road and pedestrian safety concerns mean special treatments are needed to emphasise the unusual nature of contra-flow public transport vehicle flows |
| Jumping the queue<br>– Q jump lanes<br>– bypass lanes<br>– freeway access ramps | ● Intersections are major delay points for public transport vehicles. Often this is manifest in waiting in queues of vehicles which are also delayed<br>● Q jump or bypass lanes mean providing road space for public transport vehicles at intersections so they can bypass queues and pass quickly through the intersection<br>● Q jump lanes can be provided by removing kerbside parking and introducing a short exclusive lane. The length of the lane is designed relative to the longest queue<br>● Alternatively short segregated lanes or measures to merge traffic prior to intersections can be introduced to create space<br>● Freeway access ramps are similar version of the principle used to access freeways ahead of ramp queues |
| Public transport t gates (see Figure 25.3, top) | ● Public transport gates enable public transport vehicles to pass a road barrier banning other traffic<br>● Gating is an effective strategy to control through traffic flows in busy streets but at the same time to provide public transport travel time benefits over all other modes<br>● Gating can involve the use of pits or raised platforms where passage is only possible with vehicles which have the wheelbase/bogey characteristics of public transport vehicles. Another approach is to actively detect vehicles and raise/lower a physical barrier<br>● Gating is not a common approach. However it has proven effective in minimising through traffic and providing good priority to public transport vehicles in congested European CBD's such as Gothenburg<br>● Provision of contra-flow lanes in some CBD's provide a similar form of gating access which other vehicles cannot use |

*Table 25.1* (continued)

| Measure | Details |
|---|---|
| Public transport no turning exemptions (see Figure 25.3, bottom) | ● Permitting public transport vehicles turns on the road network which other vehicles cannot make is a smaller version of public transport gating. It means generally shorter journey times on public transport routes. However it needs careful design to ensure other traffic is not encouraged to make turns as well as public transport vehicles |
| Street planning | ● In general street planning measures which speed up all traffic have the net impact of also speeding up public transport vehicles since they share the same road space<br>● However some street planning measures can provide more a subtle ways of providing priority to public transport:<br>– General road orientation – as noted earlier, general road layout orientation can assist public transport vehicles by avoiding right turns for buses. In addition road layout can have public transport route alignments in mind when networks are being developed<br>– Lane widths – wider lane widths for kerbside buses makes it easier for buses to bypass stopped or slower vehicles such as cycles<br>– Pedestrian crossing locations – traffic turning at intersections often delay public transport vehicles when they are waiting for pedestrians crossing side roads. Moving pedestrian crossings away from intersections can reduce turning traffic queues<br>– Junction incursion bans – many jurisdictions have junction boxes which ban traffic entering junctions unless their exit road is clear. This can be useful in avoiding delays to public transport (and other) vehicles passenger through the intersection on cross roads |

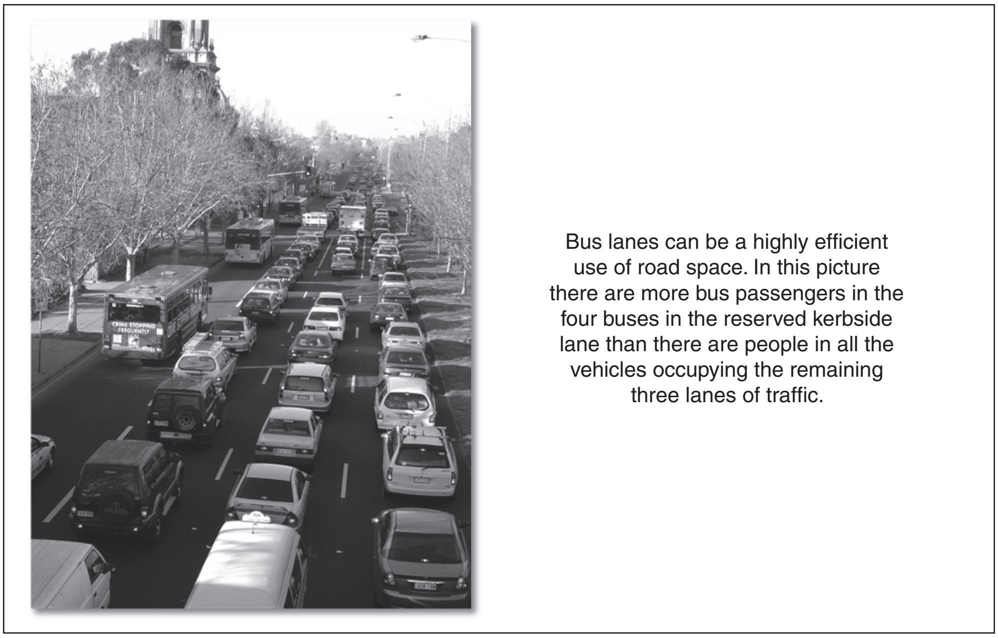
*Note:* CBD = central business district.

*Source:* Based on Austroads (2002).

**Approaches to Priority Justification/Priority Benefits**

A number of 'warrants' which identify likely thresholds for justifying priority have been identified in the traffic engineering research and practice literature. For example the US *Highway Capacity Manual* (Transportation Research Board 1994) identified that bus lanes were only justified at locations where there were at least 30–40 buses per hour. These approaches are based on simple travel time trade-offs between bus and traffic passenger travel times. Another more sophisticated method, but again based on a simple view of travel impacts, is suggested by Vuchic (1981) who assesses the justification of a bus lane as being justified when the buses using it carry as many people as are in the other lanes in cars. He uses this concept to identify the volume of public transport vehicles required to justify a public transport lane as follows:

$$q_b \geq \frac{q_a}{N-1} x \tag{25.1}$$




*Source:* Author's photograph.

*Figure 25.2 Example bus lane*

where
$q_b$ = volume of public transport vehicles
$q_a$ = volume of auto traffic
N = number of traffic lanes
X = (average auto occupancy/average public transport vehicle occupancy).

A range of studies have undertaken before/after monitoring of public transport priority schemes including both road-space priority measures (mainly bus lanes) (Flachsbart 1989; Anlezark et al. 1994; St. Jacques and Levinson 1997; Levinson et al. 2003; Ernst 2005; Currie 2006b; Barr et al. 2010) and traffic signal priority measures (Furth and Muller 2000; Kittelson & Associates et al. 2003; Smith et al. 2005; Zheng et al. 2009). A 'meta' study summarizing the major outcomes of these studies was undertaken as part of an Australian Research Council funded project to understand evidence on the impacts of priority systems (Goh and Currie 2012). The results are summarized in Figure 25.4.

Figure 25.4 indicates that for road-space measures; as a general rule, grade separated busways (ROW A) achieve higher savings in travel time as a share and in absolute terms per route kilometre compared with the other measures shown. Average mid-range savings in time as a share of total travel time were 46 percent for grade separated busways, 31 percent for at-grade segregated busways (ROW B) and 21 percent for at-grade exclusive and mixed use bus lanes (ROW C). Savings in travel time per route kilometre (Figure 25.4, bottom left) have a similar pattern, however, at-grade segregated busways

**Example public transport gate in Wellington, NZ**

Here a contra-flow bus lane provides a link in the road network which general traffic cannot make. Also note the bus lane uses greencoloured roads. This standard acts to make it clear to all road users that the road is exclusive to public transport.


**Turn ban public transport exception**

Here buses are permit to make turns which other traffic cannot.

*Source:* Authors photographs.

*Figure 25.3 Public transport gates and turn bans*

show some higher benefits per route kilometre compared with grade separated busways. This is thought to be due to high savings reported on one component project in the data which might be seen as an unusual data point or outlier. Nevertheless the data implies that per route kilometre, grade separated busways/at-grade segregated busways average around 1.7/1.9 minutes' savings in travel time per route kilometre and that these savings are typically at least three times larger than comparable at-grade exclusive and mixed use bus lanes.

For traffic signal priority measures (Figure 25.4, right) there is a large range in performance with European examples (for example, Eindhoven) showing higher performance. Overall savings in travel time have ranged between 0 percent and 89 percent with a mid-range value of 16 percent. It is rare to see no benefit resulting from traffic signal priority measures from the published data. Savings in traffic signal delay are generally

*Table 25.2 Typology of public transport priority measures – traffic signal measures*

| Measure | Details |
|---|---|
| *Passive signal priority* | |
| Shorter cycle time | • On average shorter cycle times mean more opportunities for public transport vehicles to pass through signals on green. It also shortens red time |
| Priority movement phase cycle repetition or phase splitting | • Light phases required for movement of public transport vehicles are used more than once during a cycle. This can substantially reduce effective cycle times for public transport vehicles |
| Green priority weighting | • The proportion of green time given to a public transport phase can be weighted higher than total traffic flow on that phase would otherwise have |
| Turning phasing design | • Intersection turns from the kerbside lanes often cause traffic delays due to pedestrians delaying turning vehicles. This can delay kerbside public transport operations. Alternatively trams operating in median lanes are frequently delayed by right-turning traffic. The introduction and timing of traffic turning phases can act to clear the paths of public transport vehicles |
| Signal linking and green waves | • Signal timings can be offset in a progression between a series of linked signals. These can be timed relative to public transport operating speeds and scheduled times between the signals |
| Time of day phasing variation | • Can operate as a part of green waves and linking signal progressions to public transport vehicle speeds which vary by time of day<br>• Another approach is to adjust phases in peak and off-peak directions |
| *Active signal priority* | |
| Green extension | • Green time is extended when a public transport vehicle is detected. Extension is as long as required for the vehicle to clear the lights |
| Green early start | • Conversely to the above, when a public transport vehicle is detected and the lights are red, an early start green phase is introduced |
| Special public transport phase/ bus sluice | • This can include the use of B (bus) or T (Tram) lights to undertake a special public transport only turn phase<br>• The bus sluice is a special bus only traffic-light phase to enable a vehicle to pass in front of other traffic so it can cross traffic lanes unimpeded by traffic. This is usually for difficult right turns which must be made from a kerbside lane or left turns from a median lane |
| Phase suppression | • In more complex phase sequences a phase can be omitted from the cycle and reintroduced later to enhance public transport flows through the lights |
| Priority phase sequences | • Here a special phase or sequence of phases is introduced to clear turning traffic obstructing median trams (right-turn traffic) or kerbside public transport (left-turn traffic) |
| Pedestrian crossing activation | • Where buses have difficult unsignalized turns into heavy traffic streams from side roads an innovative approach is to have vehicles activate pedestrian signals on the main road to create gaps in traffic |
| Phase compensation | • To balance the immediate effects of changing cycles to permit public transport priority, providing longer than normal cycles on those phases which were delayed is warranted. This can act to readjust traffic flows to create a more balanced system |
| Flexible window stretching (FWS) | • A more specific application of many of the above applications within the SCATS[1] traffic control system. FWS involves the use of early starts or green extensions as well as phase compensation. It is only used for bus. |

*Note:* [1] SCATS = Sydney Coordinated Traffic Control System; a common area traffic signal control system in Australian cities.

*Source:* Based on Webster and Bly (1976); Austroads (2002).

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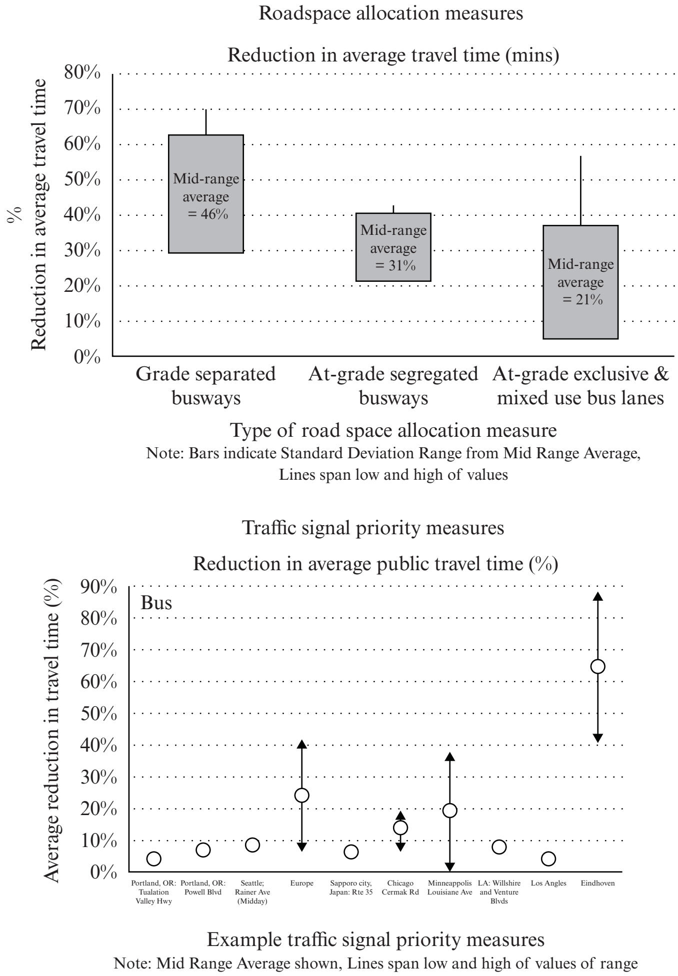
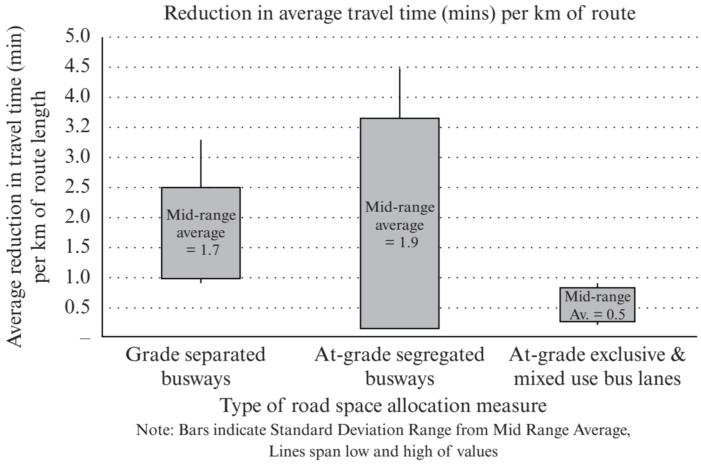



*Source:* Goh and Currie (2012).

*Figure 25.4 Synthesis of evidence of travel time and delay impacts of road space and road time (traffic signal) priority measures*

higher than travel time savings, ranging in value between 6 percent and 80 percent with a typical mid-range value of 37 percent. There is some suggestion from this data that bus savings in intersection delay (typically around 42 percent) may be slightly higher than tram (typically 24 percent) but there are only a few data points to base this on, hence such comments are speculative.

In practice the above performance data show high dispersion which may be expected because the circumstances of any particular implementation are variable. In addition, there is much debate in the literature suggesting that simple travel time and delay metrics are a very limited way of viewing priority system impacts. As a result, approaches to



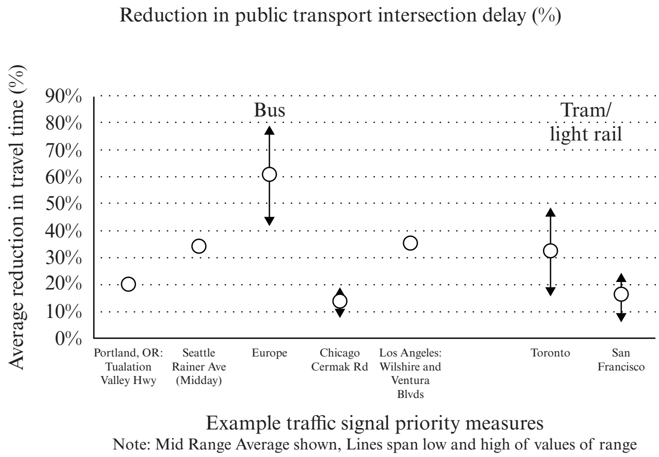
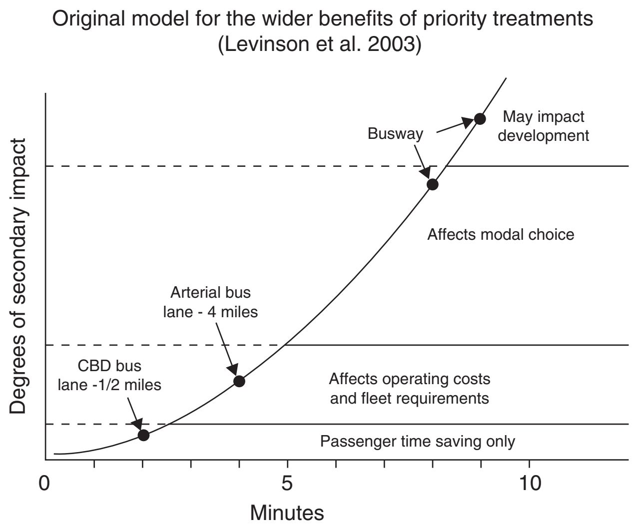




*Figure 25.4* (continued)

justifying priority based only on travel time impacts are now widely considered simplistic (Currie et al. 2007). For example the mode shift impacts of giving priority are rarely even considered. Decisions often reflect the professional background of the decision-makers (traffic engineers in road authorities) who fail to see benefits in terms of improved public transport reliability or fleet size impacts. Few studies even consider the costs of implementing priority (Currie et al. 2007). Research is now clear that there are far wider concerns than just travel time trade-offs between public transport and road users. Indeed, more recent approaches to exploring the justification of priority adopt an economic evaluation framework exploring costs and benefit trade-offs for all road users (Department of Transport Local Government and Regions 1997; Currie et al. 2007; Chisholm-Smith 2011).

A useful model exploring the wider impacts of public transport priority systems on transport is provided by Levinson et al. (2003) and was later updated by Currie and



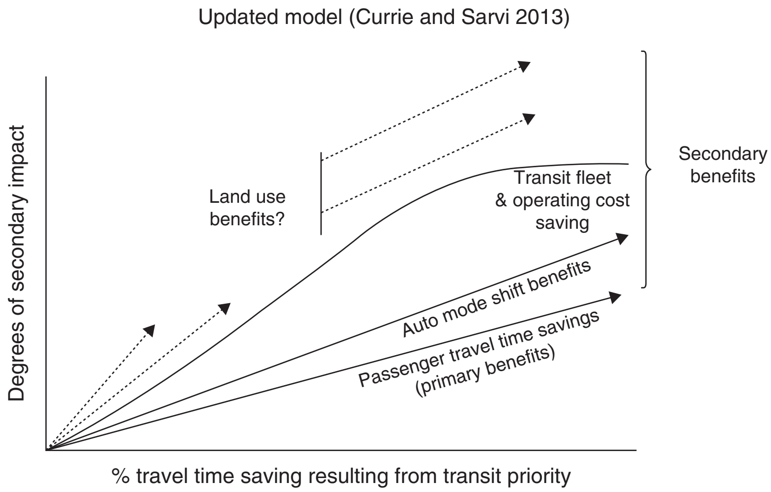




*Figure 25.5 Original and updated models for the secondary benefits of public transport priority systems*

Sarvi (2013), as shown in Figure 25.5. The original model suggested priority systems initially generate passenger travel time savings, then fleet size and operating cost savings for public transport, followed by mode shift and, finally, land use development impacts. These impacts are suggested to occur sequentially after increasing thresholds of travel time savings resulting from priority. The updated model (Figure 25.5, bottom; Currie and Sarvi 2013) is based on empirical analysis of travel time, mode shift and fleet size impacts of priority schemes. This demonstrated that, rather than being sequential and exclusive, secondary benefits occur at increasing scale and occur together consecutively as travel time benefits of priority increase. Fleet size and operating costs savings were shown to be substantial (a 30-second saving in running time for Melbourne trams saved five peak trams worth over AU$30 million in addition to operating cost savings). However, fleet savings plateau above a threshold of travel time savings.

More recent research has also demonstrated that considerable road safety benefits might be associated with public transport priority projects (Goh et al. 2013). Priority treatments (bus lanes and signal priority) on buses in Melbourne were shown to have a before/after reduction in total crash history on roads of 18 percent, including an impressive 31 percent reduction in the important fatal and serious crash group. Analysis of trend data suggests this is a 14 percent safety improvement effect; lane treatments were shown to have a larger net effect (–18 percent) than sign priority treatments (11 percent) (Goh et al. 2013). Later analysis has linked these safety effects to removing stopping buses from the traffic stream which eliminates many rear end and merging crashes as traffic avoid stopping buses. Bus lanes acting as a barrier to off-road crashes, and improved lines of sight of emerging side-road traffic as a result of bus lanes have also been linked to safety effects (Goh et al. 2014).

## Lessons Learned

The following comments provide some technical guidance on issues in priority implementation based on practical experience.

### Creating bus lanes by removing (reallocation) of traffic lanes versus adding new lanes (road expansion)

Traffic authorities do need to concern themselves with the negative impacts of removing road lanes to create a bus lane since it is likely to cause delay to prevailing traffic. Some authorities have added new lanes for the specific purpose of bus lanes, negating this concern. However, this is expensive.

### Traffic compliance and interferences in lanes

Lanes are of no value if traffic rules to exclude them are not complied with. Policing of lanes is an obvious solution but is hard to implement since the police often have other concerns and limited time availability. Automatic policing is possible and lane cameras are feasible (used in Sydney) as are cameras on buses (London). Complex lane compliance rules do not lend themselves to compliance. For example, turning traffic is permitted access to bus and tram lanes in many cases, but the length of access to lanes and in what circumstances access is permitted make understanding the rules harder. A public education campaign to better educate drivers about Melbourne tram lane rules had very little impact, with many drivers not really understanding the rules in any depth (Currie 2009).

### Short lanes do not work

There is now evidence that shorter tram and bus lanes are ineffective, particularly in busy traffic contexts (Currie et al. 2007; Mulley 2010). Short lanes imply traffic queues as lane entrances and merging traffic conflict at lane ends. Delays to buses and traffic caused by these merging zones have to be minor to balance the benefits which a short lane provides. Traffic dislocation and delay can negatively affect buses as well as cars.

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**Traffic signal priority doesn't work in congested/saturated traffic**
If traffic is congested, buses/trams cannot access signals even if they are green. Hence, a major need for effective traffic signal priority is free-flowing traffic. This is why many advanced signal priority systems have 'conditional priority'; priority only provided if traffic flow is below saturation, for example, the London scoot traffic system (Hounsell et al. 2004). An alternative to this strategy is to ensure traffic volumes near traffic signal priority routes are below a certain threshold to ensure free flow of vehicles. This is termed traffic metering and is an approach adopted for the successful Zurich tram traffic signal priority system (Nash and Sylvia 2001). The system in Zurich is implemented through 'gating' access of traffic into the central area using traffic signals. An automatic system holds back traffic to ensure volumes are manageable. Traffic signal priority savings to trams are significant, and central area traffic is never too high and quite comfortable for pedestrian as well as tram travel.

**Traffic signal priority for early running trams/buses does not make sense**
Any public transport vehicle which is running early and is provided with signal priority will operate even earlier than they otherwise would have. For this reason many advanced traffic signal priority systems provide 'conditional priority', that is, conditional on the vehicles running late.

**Approach stops make traffic signal priority ineffective**
Bus or tram stops on the approach side of intersections act to make for wasteful use of traffic signal priority. A critical part of making traffic signal priority work is predicting the time when public transport vehicles will arrive at the signal. This prediction is then used to adjust the signals such that lights are green. If predictions are wrong, and the bus/tram is delayed, green time might be wasted. One factor commonly causing incorrect time predictions is the presence of stops approaching intersections. Variation in their use mean that often public transport vehicles are delayed. The solution is to relocate these stops to the departure side of the intersection.

**Active traffic signal priority is more precise but more expensive/complex**
Being able to provide priority only when public transport vehicles are there makes more sense but is complex and expensive to provide.

**Uncertainty about commercial traffic signal priority systems**
Many traffic signal priority systems are provided by commercial companies with copyright-protected algorithms. This often acts as a barrier to better understanding how they work. Some authorities have used 'hardware in the loop' systems to better understand how priority works; this is linking of area traffic control systems to microsimulation models such that they can test changes to road design and traffic signal priority settings.

**Road authority buy-in and reluctance**
In general, road authorities have more concern and experience in managing roads than public transport. It is natural to be concerned about how new technologies are adopted that might affect core road markets. A review of Australian traffic signal priority system

implementation found that in practice many traffic signal priority had been withdrawn because road authorities failed to see net benefits and/or had concerns about how systems would work in practice (Currie 2006a). Authorities are also keener to publish success stories than to share learnings resulting from system failures.

**Need for public transport regulatory adjustment**

It is increasingly common for bus/tram services to be operated under performance-based contracts. The provision of road-based public transport priority is rarely considered when these contracts are designed. They raise issues of who pays and who benefits from priority schemes. In Europe special contracting alliances are made between road authorities and commercial bus companies to achieve priority investment and to share benefits (for example, Quality Bus Partnerships in the UK). There is a danger that the benefits of priority schemes put forward by road authorities are not passed on to public transport users if arrangements for adjustments in contracts are not made. The author has experienced examples where the benefits of priority were squandered for the benefit of an improved time performance contract outcome by operators.

**Need for partnership between road authorities and public transport planners**

As can be seen from the text above, there has been a historical bias towards road authorities limiting the design, scale and benefits of priority schemes as a result of limited 'road based' thinking. Design of schemes from both sides are needed.

## 5 PUBLIC TRANSPORT FACILITATION

Public transport facilitation is the adoption of general traffic engineering design principles which make possible effective and efficient flows of buses and trams. Where buses and trams operate in mixed traffic (ROW C), roads need to be designed so that public transport vehicles can physically move on these roads at reasonable speed and level of safety. This is not such an easy requirement in smaller residential blocks when vehicles can be large and often involve a low floor design. Public transport facilitation involves ensuring these vehicle movements are possible. It also concerns the more strategic layout and design of roads. It is inefficient for a bus or tram to have to turn around and return down a street which it has already travelled. Hence road layouts involving cul-de-sacs are inefficient from a public transport viewpoint and should be avoided.

Austroads (2002) has made a differentiation between strategic and local levels of facilitation for buses. Table 25.3 (based on Austroads 2002) shows some of the key measures identified with regard to strategic facilitation. This concerns the overall layout and design of roads relative to public transport. In general it is prudent for traffic engineers to understand the specific requirements of the public transport vehicles being used in their area of responsibilities. These vehicles can change over time. Recent trends towards the use of 'ultra-low floor' and 'stretch rigid' buses are examples where existing road infrastructure can be found wanting when new public transport vehicles are deployed.

Most strategic public transport facilitation measures apply equally to trams and light rail as well as buses. In general these issues will be considered during the design and construction of rail public transport systems. Traffic engineers in this case are more

*Table 25.3 Traffic planning measures in strategic public transport facilitation (bus)*

| Facilitation measure | Rationale | Approach |
|---|---|---|
| Land use cell connectivity | Development sites can be difficult for buses to move between blocks. Making right turns into a busy traffic stream is difficult. Some land blocks have a single entry and entry point which result in congestion and inefficient bus movements | Staggered T intersections where left turns to access main roads are a feature. Multiple entry and exit points to development blocks should be provided to reduce cases where buses must retrace their steps along the route |
| Subdivision permeability | Buses often have to retrace their steps in some development areas owing to poor road connectivity | Roads providing relatively straight through pathways should be provided. Adequate road widths are necessary for public transport vehicles |
| Pedestrian accessibility | Frequently, access to public transport stops is only available form one direction and indirect. Hence longer walks are required to access stops | Public transport stops should be located close to road crossing points and pathways connecting into other streets and residential development |
| Turns across major roads | Bus routes are often delayed by right turns into long and continuous unsignalized traffic flows | Roads should be designed to give preference for left turns for buses. Wherever right turns are necessary, the provision of roundabouts or traffic signals should be provided or 'seagull' acceleration lanes within the road medians |
| Carriageway and lane widths | Large vehicles need sufficient clearance for safe operation | *Straight road – one way traffic* – Minimum carriageway width between 7.4 and 8.0 metres to permits traffic to bypass stopped buses. Lane width between 3.7 and 4.0 metres. Where kerbside with cycles a width of 4.4 metres enables safety cycle passing<br>*Straight road – two way traffic* – Minimum carriageway width of 7.0 metres. Minimum lane width of 3.5 metres (can be reduced to 3.1 metres in some cases)<br>*Lane widths curved roads* – Should be increased beyond normal design to accommodate larger public transport vehicles. |
| Road profiles | Large public transport vehicles operate slowly on large road inclines. They also require clearance from the road surface for safe manoeuvring | Gradients should not normally exceed 6%. Small connecting ramps can be up to 10% (maximum). Cross fall should be limited to 5% to assist passenger stability |
| Road turns and curves | Turning large vehicles in confined conditions can be dangerous to other traffic and can cause delays | Consideration of the vehicle swept path should be given in each case |
| Bus stops and bays | Road geometry should encourage safe bus stops including adequate rear-view vision. | Bus bays enable buses to be removed from traffic flow. However consideration for re-entry to flow should be made |
| Stopping and parking restrictions | This ensures that buses may access bus stops easily and are not delayed on bus lanes | Clearways at bus stops are mandatory in many locations. Parking and stopping restrictions are also used |
| Priority enforcement | It is not uncommon to see bus lane measures breached in high traffic areas | Improved enforcement procedures including on and off vehicle surveillance can be used |

*Source:* Adapted from Austroads (2002).

concerned with the impacts of fixed public transport infrastructure on other road traffic flows adjacent to light rail schemes.

Table 25.4 (also based on Austroads 2002) shows some of the features of local-level public transport facilitation. These measures concern issues that arise when buses operate in areas where local area traffic management schemes have been introduced to enhance road safety and to reduce through-traffic movements in residential areas.

## 6 CONCLUSIONS: UNDERSTANDING 'STATE OF THE ART'

Defining the 'state of the art' in managing public transport on roads requires a basic understanding of the aims of transport policy in a city, including a knowledge of its road infrastructure, traffic levels and the operational performance of its public transport system. Figure 25.6 presents a theoretical model which acts to define state-of-the-art public transport priority, given the context of city public transport policy with a view to guiding policy responses in this domain. Previous research has demonstrated much variation in the aims of transport policy concerning public transport between cities (Nielsen et al. 2005). For cities seeking to provide public transport as a complete alternative to the car for all travel, redesign of on-road public transport to provide 'total priority' through provision of ROW A/B streets is preferable. However, even with ROW C contexts 'high priority' can be provided, for example, the Red Route program in central London. Here complete redesign of all aspects of roads to give priority to buses has been implemented. Traffic signal priority for buses is also important but, at the 'high priority' level, greater preference for public transport over car is required. Signal priority may be at the standard of 'at-grade railway level crossings', that is, what is often termed 'signal pre-emption' (public transport always gets through first time; traffic must always wait for trains).

Many cities see public transport as mainly a solution for peak levels of traffic congestion. In this case 'peak-only priority' represents the state of the art in design. This involves peak-only bus lanes and signal priority. Active priority makes better sense here because the aim is to reduce traffic queues. Traffic metering may also be preferred.

Other cities are dominated by car traffic, and public transport has a mainly social role; filling in gaps in travel for those without a car. In these cases 'state of the art' for priority involves 'subservient priority'; giving lane space and traffic signal time to buses, but also being sympathetic to the dominant transport provider – car traffic. Priority can still be provided but only at low cost and at high benefits to public transport. High-occupancy vehicle lanes are a good option in these contexts, that is, giving priority to cars with many passengers as well as buses.

In practice all cities probably exhibit aspects of policy of each of the types shown in Figure 25.6 in separate parts of the city; hence the state-of-the-art priority implementation should vary and take account of localized issues and conditions.

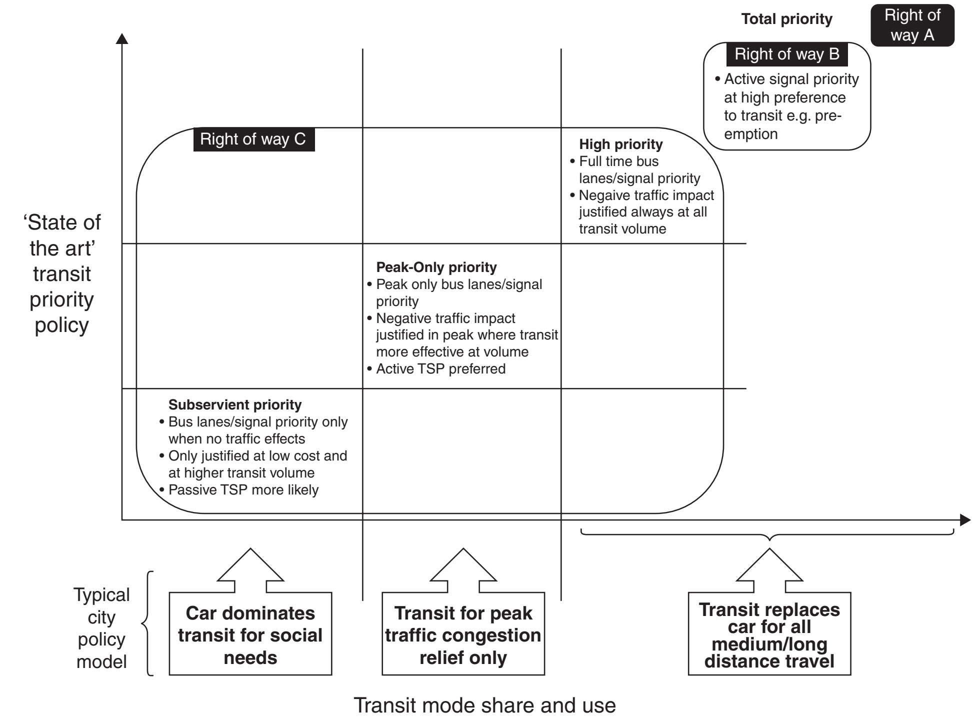
Regardless of these localized variations, the following list might be regarded as the major elements of a high-quality state-of-the-art approach to managing public transport on roads:

- Provide lane priority and enforce compliance as much as is feasible.
- Provide active traffic signal priority and make it conditional on traffic saturation,

*Table 25.4 Traffic planning measures in local level public transport facilitation (bus)*

| Facilitation measure | Rationale | Approach |
|---|---|---|
| Bus boarders (sometimes called bus bulbs) | Parked traffic often encroach on bus stop zones making it difficult for large vehicles to access stops effectively | Pedestrian pavement is extended into the road and the bus permitted to load/unload in the kerb extension (or reverse embayment) |
| Bus stop run ins and outs | In heavy traffic buses need a large traffic gap to exit and run up to speed | Provide bus acceleration and deceleration lanes out of traffic streams for buses to access stops |
| Bus stop location | It is wasteful for buses to be delayed at intersections and also at stops | Co-locating bus stops at intersections can save travel time. Location near traffic calming devices can be safer for pedestrians accessing stops |
| Roundabouts | Roundabouts slow buses down. In addition it can be necessary for the front and rear overhang of the vehicle to pass over the footpath to make difficult turns. This can be dangerous and needs management | The swept path needs of large vehicles should be considered when designing roundabouts. In general rigid buses require a central island radium of 6 metres at 5 kph and 8 metres up to 15 kph. Articulated buses need larger central island widths (up to 12 metres). |
| Road humps, speed cushions and table | Road humps not only delay buses and make an unpleasant journey for drivers, they can also be unhealthy for drivers and are banned in some places | Limited road humps on bus routes are better than larger sized humps. An alternative is speed cushions with widths designed to enable buses to straddle the cushion. Speed tables are not welcomed on bus routes since they slow down buses. Consideration needs to be given to vertical clearance on tables |
| Slow pinch points | This can slow buses as they have to ensure accurate manoeuvring | If these are necessary they are better near bus stops where buses are moving more slowly |
| Mid-block islands | Less problematic for buses | Minimum lane widths should be 3.1 metres but 3.5 metres is more desirable |
| T intersection deviation | Buses can find it difficult to turn at T intersections | Swept path analysis is again desirable. Minimum lane widths are 5metres (continuing road) and 6 metres (entry lane) 3.3–3.5 metres (terminating road) |
| Intersection splitter island | Local traffic measures can include splitter islands at cross roads. These cause difficulties for bus turning movements | Reference to bus swept path analysis is needed. In general carriageway width should be 7.4 metres and lane width 3.1 metres. The height of splitter islands should have reference to bus clearances |
| Chicanes | These can slow down buses | In general these are not preferred on bus routes. However some design can enable large buses to run over the chicane |

*Source:* Adapted from Austroads (2002).




*Source:* Authors concept

*Figure 25.6 Conceptual model for 'state of the art' in on-road public transport priority design*

late running and public transport loading. Provide phase compensation to reduce traffic queues where feasible. Ideally, traffic metering should be provided to keep traffic running smoothly. Relocate approach stops to departure sides.

- Facilitate public transport operations by ensuring the road design and the network of roads fits well with bus or tram operations, including route design and bus/tram vehicle flow and access.
- Ensure safe, secure and ease of access and egress of public transport vehicles to stops, terminals and depots

Future developments in the management of public transport on roads concern mainly new technology possibilities of better managing bus and traffic interaction. Intermittent bus lanes are a concept technology for a 'managed road' where buses are provided with priority only when they are there. Two trials have been undertaken, neither were entirely successfully, however, in both cases elements of promising results were identified (Viegas et al. 2007; Currie and Lai 2008). Research has noted the lack of a network focus on the provision of priority design and has demonstrated theoretical advantages from a network-based approach (Mesbah et al. 2008). Automated vehicle control systems are another technology development which might see the potential for provision of priority through automated priority design. In this context priority would be built into the rules of vehicle control systems even without the direct knowledge or concern of drivers. As lessons learned from existing priority system have shown, automated technologies will need to incorporate elements such as conditional priority to keep traffic flow efficient.

In the interim, most cities will need to manage the technologies they currently have to best manage public transport on roads. For most this implies a measured balance between the use of road space and intersection time to ensure a maximum throughput of passengers/riders though our busy city streets.

## NOTE

1. This chapter an updated and much expanded version of the following source: Currie, G. (2004), 'Planning and design for on road public transport', *Traffic Engineering and Management*, Institute of Transport Studies, Monash University, Melbourne.

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