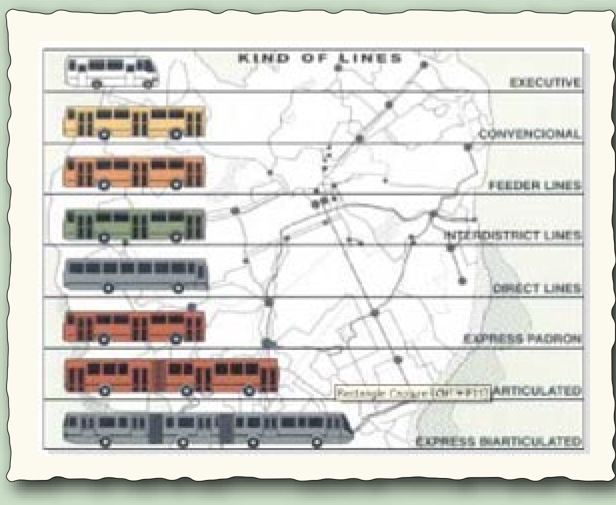
Bus Rapid Transit
Planning Guide

June 2007

Part II – Operational Design

CHAPTER 7



Network and service design

CHAPTER 8

System capacity and speed

CHAPTER 9

Intersections and signal control

CHAPTER 10

Customer service

7. Network and service design

"Always design a thing by considering it in its next larger context—a chair in a room, a room in a house, a house in an environment, an environment in a city plan."

—Eliel Saarinen, architect, 1873–1950

The starting point for the design process should not be the infrastructure or the vehicles. Instead, the system should be designed to achieve the operational characteristics that are desired by the customer. From the customer's perspective, some of the most important factors affecting their choice of travel modes are whether the service will take them where they want to go and how long it takes.

This chapter addresses the system's coverage across the wider network of a city's principal origins and destinations. Additionally, this chapter discusses the various factors that affect the system's convenience and ease of use. Does the trip involve many difficult transfers or can one access desired destinations within a single routing? If transfers are necessary, will they involve cumbersome walks across intersections and grade separations or are the transfers easily facilitated across a platform protected from adverse weather?

In some instances, operational decision-making can involve trade-offs. The most economical and efficient system may impose transfers on customers while direct services may prove to be more costly. Providing the most effective service frequently requires a significant change in how existing public transport operators work, but changing the status quo for operators can often be politically difficult. Balancing the various factors between customer service, cost efficiency, and operator relations requires a full understanding of the operational options and their implications.

The topics discussed in this chapter are:

7.1 "Open" versus "closed" systems

"Sometimes we stare so long at a door that is closing that we see too late the one that is open."

—Alexander Graham Bell, inventor, 1847–1922

The degree to which access is limited to prescribed operators and vehicles can have a significant impact on vehicle speeds, environmental impacts, and the system's aesthetic qualities. On one extreme, there are busways that are essentially high-occupancy vehicle lanes (HOV). In this case, access is granted to any vehicle carrying over a certain number of passengers. Bus corridors such as Avenue Blaise Diagne in Dakar, Oxford Street in London and the Verazano Bridge in New York allow both buses and taxis. The Ottawa Transitway permits both urban BRT vehicles as well as inter-city bus services. Conversely, the Bogotá and Curitiba systems limit access to only prescribed BRT operators and special BRT vehicles.

If there are no restrictions on operator access or the types of vehicles, the busway may perform inefficiently. As more vehicles enter the busway, the resulting congestion at stations and intersections will greatly reduce average speeds and thus increase customer travel times. Limiting access to an optimum number of operators and vehicles can help to ensure system capacity and speeds are maximised and maintained over time. However, placing restrictions on operator access generally requires changing the way the public transport sector is regulated and managed. While such a re-organisation can be a positive development, it often requires a great deal of political will and political leadership.

Emergency vehicles, such as ambulances, are generally permitted access on most BRT systems (Figures 7.1 and 7.2), whether it is an open or closed system. This public service provides an additional motivation for approving a BRT project, especially since many rail options are not be compatible with emergency vehicles. In

Fig. 7.1 and 7.2
In cities such as Quito, the exclusive busways also permit emergency vehicles to avoid traffic delays and respond more quickly to those in need.
Photos by Lloyd Wright

many cities, mixed traffic congestion significantly inhibits emergency access and delivery. By facilitating rapid emergency services for the injured and critically ill, the BRT system is in effect helping to save lives.

Some cities also permit "official" vehicles to utilise the busway. This usage may include presidential and ministerial motorcades as well as travel for low-ranking public officials (Figure 7.3). The justification for such usage can be somewhat questionable. Certainly, for the highest ranked officials, such as the national president or prime minister, the exclusive busway does allow for potentially safer movements, which can be important in nations where terrorism or other security threats may exist. The usage by lower-ranking officials is harder to justify and can ultimately have a highly detrimental impact on system speeds and capacity. In Quito, sometimes the expropriation of busway space even extends to public utility vehicles, such as garbage trucks (Figure 7.4). While it is understandable that utility companies would like to take advantage of rapid access on the busway, the presence of such vehicles can do much to hinder proper BRT operation.

7.1.1 Defining "open" and "closed" systems

Systems that limit access to prescribed operators are known as "closed systems". Typically, this access is granted through a competitive selection process. In general, the highest-quality examples of BRT, such as Bogotá and Curitiba, utilise a closed system structure. In these cases, private companies compete for the right to provide public transport services under a process of competitive tendering. The number of operating companies and the number of vehicles utilised will largely be a product of optimising customer conditions. These systems also only permit vehicles with highly-defined specifications to operate on the corridor.

By contrast, systems that have implemented a busway system without any sector reform or any exclusivity are known as "open systems". In such cases, any operator that previously provided collective transport services will retain the right to provide services within the new busway. In

Fig. 7.3
When usage of the exclusive busway by lower-ranking governmental officials becomes common place, then there can be negative impacts on the efficiency of the system.
Photo by Lloyd Wright

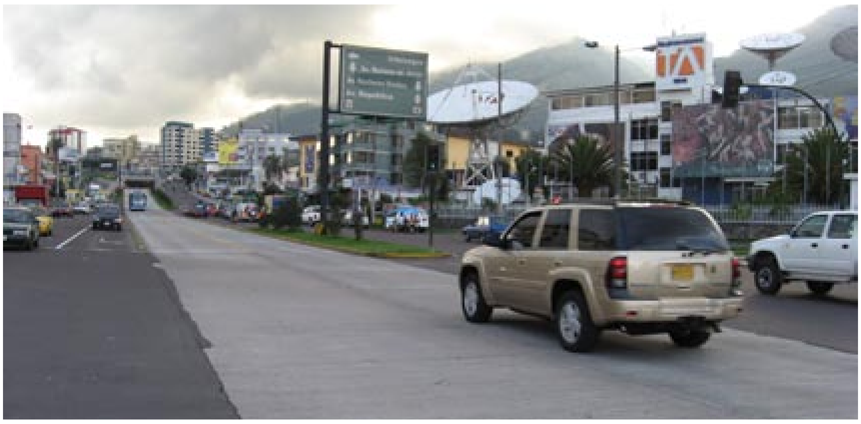


Fig. 7.4
In Quito, even garbage trucks take advantage of the exclusive busway.
Photo by Lloyd Wright

Fig. 7.5
Kunming employs an "open" BRT system, using segregated busways but with few routing or structural reforms.
Photo by Lloyd Wright

an open system, operators will largely continue to run the same routes as they did previously. Thus, the operators will tend to utilise the busway infrastructure whenever it coincides with their previous routing, and they will likely also operate parts of their existing routes without busway infrastructure. The systems in the cities of Kunming, Porto Alegre, and Taipei operate as open systems (Figure 7.5). Most cities with lower-grade BRT systems, or simply basic busways, utilise an open system structure.

In general, a closed structure is more conducive to efficient operations. Since the number of operators and the number of vehicles are rationally selected and carefully controlled, a closed system tends to be designed around the optimum conditions for customer movement. Further, a closed structure frequently implies that a competitive structure is in place that provides operator incentives regarding service quality.

Open systems tend to be designed principally around the preferences of existing operators, and thus not necessarily around the optimum conditions for customers. Open systems have the advantage that they do not require any fundamental changes in the regulatory structure of the existing bus services. Open systems are particularly prevalent in cities where the political will does not exist to re-organise the bus system. Since bus operating companies may represent powerful political interests, public officials may decide that maintaining the status quo will cause the least amount of discomfort to existing operators. Thus, with the exception of a bit of new infrastructure in the form of a basic busway, an open system may be otherwise indistinguishable from a standard bus service.

In reality, the division between "closed" and "open" systems is not as clearly delineated as suggested above. Some "open" systems may still exclude charter buses, school buses, airport access buses, minibuses, or intercity buses. Systems may undergo some relatively minor reforms that may partially limit operator access. In some cases, such as the Quito "Central Norte" corridor, the business structure may be partially reformed. The operational concession for the Central Norte line essentially permitted all existing operators to participate in the new busway. However, to operate on the Central Norte corridor, only vehicles of a specific type are allowed. The shift to larger, articulated vehicles did help to rationalise services in the corridor, despite the lack of complete business reform. Thus, systems such as the Central Norte may represent a partially closed system that reaps some benefits from marginal reform.

7.1.2 Impacts on operations

Perhaps the most telling difference between an open and closed system is the impact on average vehicle speeds and customer travel times. Without any rationalisation of existing services, an open system can lead to severe congestion on the busway, though a poorly planned closed system can also become congested. A closed system will tend to operate high-capacity vehicles that will likely result in service being provided every three minutes. An open system may consist of many smaller vehicles all tightly bunched with little spacing between them. Thus, while a closed system can produce average commercial speeds of 25 kph or higher, an open system will likely produce considerably slower speeds. Also, to date, some open systems have

Fig. 7.6 and 7.7
Bogotá originally operated an "open" busway system (left photo), but the resulting congestion did little to help customers. By contrast, the development of the "closed" TransMilenio system along the same corridor has proven to dramatically improve travel times and customer comfort.
Left photo courtesy of TransMilenio SA
Right photo by Lloyd Wright

been implemented without improving the quality of the vehicles utilised.

The allowed vehicle types will also greatly affect several performance indicators including boarding and alighting times and station congestion levels. A single small bus with a very small door can badly congest an exclusive BRT lane, and for this reason such buses are incompatible with high speed, high capacity BRT systems. Specifying maximum vehicle age and maintenance practices can also affect performance. Breakdowns contribute to corridor congestion. Thus, weak regulatory control over the vehicle fleet is incompatible with consistent high-speed, high-capacity, and high-quality service. Tight regulation of emissions, operating speeds, and noise are also important to protecting the environmental quality of the corridor.

Fig. 7.9
Likewise, average speeds on the open Taipei system also are affected by busway congestion.
Photo courtesy of Jason Chang

Prior to developing its TransMilenio system, Bogotá actually operated a median busway on its "Avenida Caracas" corridor. The "Avenida Caracas" busway operated as an open system, permitting all existing operators to utilise the infrastructure. The result was excessive busway congestion and average commercial speeds of approximately 10 kph (Figures 7.6 and 7.7). The busway was partially effective in improving conditions for mixed traffic but did little to improve travel conditions for transit passengers.

Likewise, the existing busways in Lima (Vía Expresa, Avenida Abancay, and Avenida Brasil) as well as the BRT systems in Kunming, Porto Alegre, São Paulo, and Taipei are also open systems and are also subject to congestion (Figures 7.8 and 7.9).

7.2 Trunk-feeder services versus direct services

"A straight path never leads anywhere except to the objective."

—Andre Gide, novelist, 1869–1951

Providing public transport service to all major residential and commercial sectors of a city can

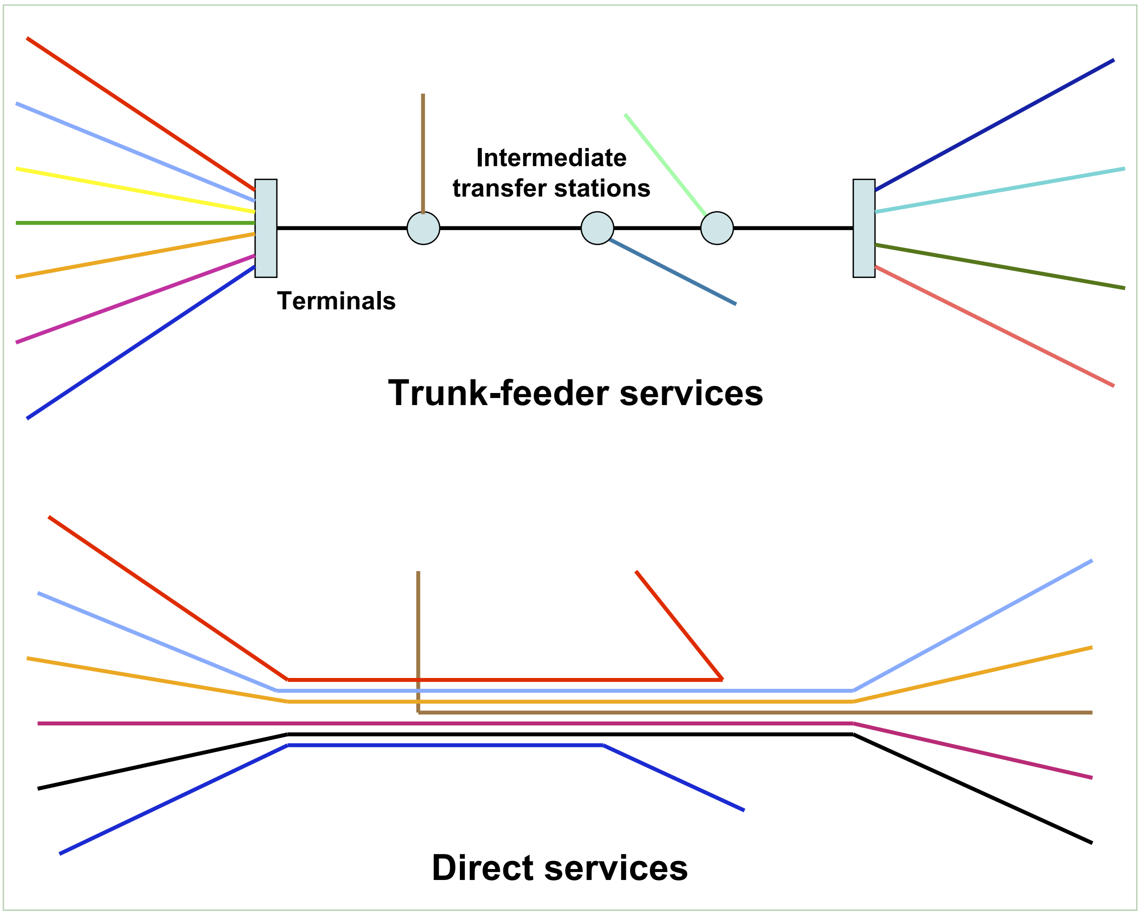


Fig. 7.10
Illustrative comparison between trunk-feeder services and direct services.

be challenging from a standpoint of system efficiency and cost effectiveness. Serving the densest portions of the city often requires a high-volume of high-capacity vehicles, while lower-density residential areas may be most economically served with smaller vehicles. However, at the same time, customers generally prefer not be forced to transfer between vehicles as transfers impose a cost in both time and convenience. The question for BRT system planners is how to balance these varying needs and preferences. Smaller residential areas do not have to be sacrificed from the system. A well-designed system can accommodate a range of population densities in order to achieve a true "city-wide" service.

In general, there are three options in terms of the overall service structure:

1. Trunk-feeder services;
2. Direct services;
3. Mix of trunk-feeder services and direct services ("hybrid" services).

Trunk-feeder services utilise smaller vehicles in lower-density areas and utilise larger vehicles along higher-density corridors. The smaller vehicles thus "feed" passengers to the larger "trunk" corridors. Many passengers utilising a trunk-feeder system will need to make a transfer at a terminal site. Direct services will have less need for feeder vehicles and transfers, generally taking passengers directly from their origin to a main corridor without the need for a transfer. Figure 7.10 illustrates the difference between trunk-feeder services and direct services.

7.2.1 Trunk-feeder services

Trunk-feeder services utilise smaller vehicles from residential areas to provide access to terminals or transfer stations, where customers transfer to larger trunk vehicles (Figure 7.11). High-quality BRT systems, such as the systems in Bogotá, Curitiba, and Guayaquil, have so far all tended to employ trunk-feeder services. Typically, the feeder service vehicle will operate on mixed-traffic lanes while the trunk vehicles will operate on exclusive busways. In many respects, the concept of trunk-feeder services is similar to the practice of hub-and-spoke operations as utilised by the airline industry.

Fig. 7.11
In trunk-feeder systems, such as Bogotá's TransMilenio, customers change from feeder vehicles (green vehicle on the left) to trunk vehicles (red vehicle on the right) at terminal sites.
Photo by Shreya Gadepalli

7.2.1.1 Advantages of trunk-feeder services

Operational efficiency

The major advantage of trunk-feeder services is the ability to closely match supply and demand, depending on the characteristics of the local area. Trunk-feeder services can increase the number of passengers per vehicle. The amount of passengers carried relative to the capacity of the vehicle (*i.e.,* the load factor) is a principal determinant in the profitability of the system. The improved load factor also makes possible a reduction in the fleet size required by a factor of three or more, reducing busway congestion and air emissions from the vehicles.

Systems with direct services will generally use a uniform vehicle size to provide services in both residential areas and higher-density trunk corridors. By contrast, trunk-feeder services use smaller vehicles to collect passengers in lower-demand residential area. The smaller vehicles are less costly to purchase and operate, and these vehicles can more cost-effectively provide a frequent service. If a large vehicle is employed in a low-density area, then either: 1.) The frequency between vehicles will be long; or, 2.) The large vehicle will operate with few passengers, making for expensive operations per passenger carried. If service frequency to peripheral areas is poor and customer waiting times are long, then many passengers will seek alternatives. In such circumstances, paratransit services may flourish while the formal bus system will receive little ridership. On the trunk corridors, a trunk-feeder service will operate larger-sized vehicles, which can provide a much higher capacity with fewer vehicles.

The efficiency gained from increasing load factors by closely matching vehicle sizes to customer demand can be significant, especially if the current system is operating with high vehicle volumes and low load factors.

Service quality

Trunk-feeder services are typically coupled with "closed system" business structures. Since most standard bus systems do not utilise trunk-feeder services, the conversion to the trunk-feeder option is typically accompanied by bus sector reform. Thus, the selection of the trunk-feeder option can also catalyse other important structural changes in concessions, contracting, and operational control.

7.2.1.2 Disadvantages of trunk-feeder services

Time loss due to transfers

The principal disadvantage of trunk-feeder services is the requirement for some passengers to transfer vehicles at one or more points in their journey (Figure 7.12). The process of transferring can be an undesirable burden for passengers, as it takes time and creates inconvenience. For a customer with baggage or with a small child, a transfer can make the journey physically difficult. In some cases, a person may elect to utilise a different travel mode if the transfer process is too cumbersome. Customers will particularly dislike transferring if they are travelling a relative short distance. In such instances, the time lost in the transfer can be equal to or greater than the actual time required to travel to the destination.

Additionally, customers tend to penalise "waiting time" more severely than "travel time". Thus, even if a vehicle operating in direct services incurs a longer overall travel time due to traffic congestion, the perception of the waiting time with a trunk-feeder transfer may make that service seem longer.

Distance travelled

The act of travelling from a residential area to a transfer station may also imply a significant detour from the intended destination. This detour factor not only affects customer travel times but also affects the efficiency of operations. The amount of additional fuel consumed is directly proportional to the length of the detour. Figure 7.13 illustrates the potential detour factor.

Infrastructure costs

Another disadvantage of a trunk-feeder service is the need to construct transfer terminals or intermediate transfer stations. These facilities typically involve multiple platforms and pedestrian infrastructure facilitating access between the different routes and services. Thus, these transfer stations will likely be more costly to construct than a standard station that does not facilitate transfers. Additionally, there are maintenance and operational costs associated with these facilities.

The main economic costs associated with a trunk-feeder service will be the amount of travel time delay due to transfers and the additional cost of building, operating, and maintaining the transfer facilities.

However, it should be recognised that not all passengers will require a transfer when utilising a trunk-feeder service. In Bogotá, approximately

Fig. 7.12
The walk between a feeder stop and the trunk station can act as a disincentive to use public transport for many.
Photo by Carlos F. Pardo

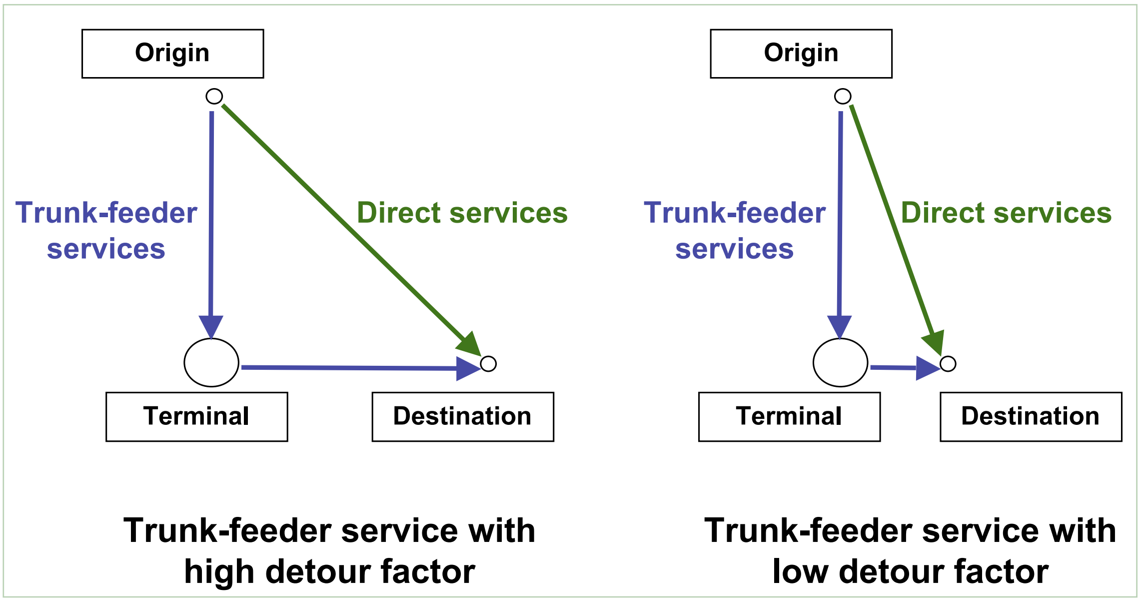


Fig. 7.13
Detour factor and trunk-feeder services.

50 percent of passengers enter the system from the feeder services. The other 50 percent of passengers enter the system along one of the trunk corridors. Additionally, not all passengers from feeder routes enter a trunk corridor, as some trips can be conducted entirely within a feeder route.

Further, the amount of time and inconvenience associated with a transfer depends greatly on the design of the transfer area. A well-designed transfer may simply involve a few metre walk across a platform to a waiting vehicle. In this case, the time and inconvenience penalty will be relatively small. By contrast, a transfer involving a walk across a busy intersection and a long wait at another station will be considerably more costly from the customer's standpoint.

7.2.2 Direct services

As the name implies, "direct services" carry a passenger directly from a residential area to a main-line corridor. Direct services are employed in several cities, including Kunming, Nagoya, Porto Alegre, São Paulo, and Taipei. In these cities, the BRT vehicles may only utilise an exclusive busway for one portion of the route. The vehicles typically operate on an exclusive busway in central areas, where demand is higher. For other portions of the route, the vehicle will likely operate in mixed-traffic lanes.

7.2.2.1 Advantages of direct services

Time savings

The principal advantage of direct services is that fewer passengers should require transfers between routes. The same vehicle carries the passenger from a residential area into the trunk corridor. Some passengers may still require transfers if they are travelling to a different trunk corridor, but overall, fewer transfers should be required. Direct services can save travel time in two ways: 1.) Reduction in waiting times at transfer stations; 2.) Potentially more direct routing to a destination. If the direct services provide a shorter and more direct route, there will likely also be some operational cost savings from reduced fuel usage.

Infrastructure costs

Systems employing direct services also forgo the need to construct terminals and intermediate transfer stations. Some interchange stations for trunk-line to trunk-line transfers may still be required. Thus, the total economic benefit of direct services will be the travel time savings plus the infrastructure savings of terminals and intermediate transfer stations.

7.2.2.2 Disadvantages of direct services

Operational efficiency

The primary disadvantage with direct services is that a single vehicle size must be used throughout the entire bus route, while passenger demand along the route may vary widely. The operator will have to choose a vehicle size that will be optimal for some part of the trip but not for other parts of the trip. The vehicles utilised by direct services are often smaller than articulated, trunk vehicles and larger than feeder mini-buses. This size compromise may imply the vehicles are not optimally designed for either location.

As a result, on trunk roads, there are likely to be a larger number of smaller vehicles operating at lower capacity than would be optimal. A lower number of passengers per vehicle will tend to increase the cost per passenger of providing the service. At very high vehicle volumes inside a BRT system, this will tend to lead to vehicle congestion and slowing bus speeds and lower system capacity. On feeder routes, the vehicles may have less manoeuvrability than mini-buses. In turn, this lack of manoeuvrability may delay average speeds as the vehicles attempt to operate on narrow streets and sharp corners.

Average speeds and total travel time

Thus, the time savings gained through avoiding transfers can be negated with inefficiencies elsewhere. The slower operating speeds, due to congestion, can more than offset the customer's time advantage from avoiding a transfer. While customers may avoid the physical inconvenience of transferring vehicles, they do not necessarily arrive more swiftly to their destination. Figures 7.14 and 7.15 illustrate the bunching of buses that may occur with direct service systems.

Meanwhile, on low demand suburban routes, the chosen vehicle type may be too large to efficiently serve the area. This vehicle will either operate nearly empty, requiring more fuel and more vehicles than are actually required, or else the

Fig. 7.14 and 7.15
To date most of the systems with direct services have suffered from congestion and bus "bunching", such as the systems in São Paulo (left photo) and Taipei (right photo). However, the congestion problems are likely due to such systems being "open" in their operational structure.
Left photo courtesy of Paulo Custodio
Right photo courtesy of Jason Chang

vehicle operator will tend to cut back on service, leading to long waiting times for passengers.

The perceived time savings gained through the lack of a transfer can also be negated through fare handling and other operational procedures. Most existing direct services tend to employ on-board fare collection and verification (*e.g.,* Kunming, São Paulo, Seoul, and Taipei). This activity can considerably delay boarding and alighting and result in long dwell times at stations. In turn, this delay will significantly increase total travel times for passengers.

Vehicles

Direct services may also imply additional costs for vehicles and/or compromises in the location of the station. Direct services operated on a median busway with median stations will require doors on both side of the vehicle. Doorways on one side of the vehicle will likely be of a wide, high-floor design providing direct access to formal trunk-line stations. Doorways on the other side of the vehicle will be smaller, stair-accessed entry points to be used when the vehicle is operating in mixed traffic lanes. When operating in low-demand areas, passengers are boarding and alighting at a curb-side shelter and not at a median station. Providing doorways on both sides of a vehicle involves an additional cost. This cost is not just the additional cost of the doorways but also the structural reinforcement required when more of the vehicle's carriage is open space. Figure 7.16 provides a schematic layout of a vehicle with two-sided doorways.

The lower load factors for direct services may also imply more vehicles are required since the same number of passengers must be moved with fewer passengers per vehicle. However, direct services may gain some economies of scale if all vehicles are identical. In contrast, a trunk-feeder system will always require the purchase of at least two vehicles types: 1. Larger, trunk vehicles; and 2. Smaller, feeder vehicles.

Additionally, since direct services imply that some large and expensive vehicles will be operating in mixed traffic conditions, this type of operation can increase accident risks as well as likely insurance costs.

Infrastructure

While direct services may avoid the cost of some infrastructure components such as transfer

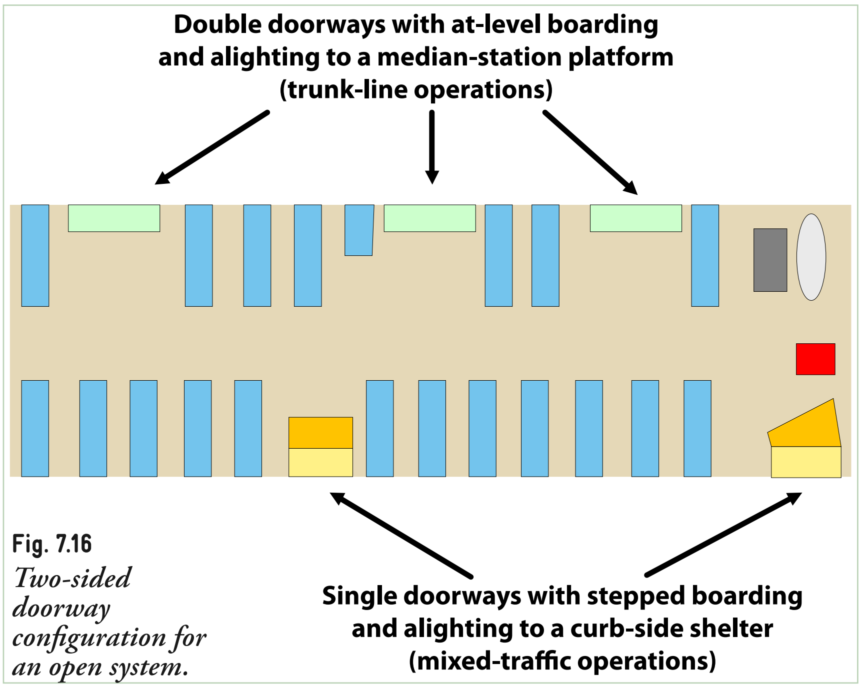


Fig. 7.16
Two-sided doorway configuration for an open system.

Fig. 7.17
The use of side-aligned stations on systems such as the Central Norte corridor in Quito can force difficult transfers between routes.
Photo by Lloyd Wright

terminals, other components may be more costly. Some systems utilise direct services with single-sided doorways. In order to accommodate both median and curbside stations, these systems employ side-aligned stations at the median. This design ensures that passengers will always board and alight on the same side of the vehicle. Figure 7.17 shows the Quito Central Norte line with side-aligned stations in the median.

This configuration carries with it several disadvantages from a cost and customer service perspective. First, unlike a central median station, the curbside stations imply that two different stations must be built for each direction of travel. The doubling of the number of stations constructed will likely increase costs. Also, splitting the stations for each direction makes transfers to other corridors quite difficult. Customers are no longer able to easily change directions during a trip, and most often this configuration implies that customers will have to walk across intersections to change corridors. A single median station allows easier platform transfers between corridors. In effect, the side-aligned stations make the routes function more as a series of independent corridors, rather than a fully integrated system.

Additionally, stations for direct service systems must often handle long queues of waiting vehicles due to the nature of the operations. In order to accommodate this quantity of vehicles, either longer station platforms are required or multiple platforms will need to be provided. The longer stations and/or platforms may increase infrastructure costs as well as increase the amount of required right of way. Passengers also frequently are not sure where along a platform to wait, and must race up or down the platform when their vehicle arrives. However, this last problem can be avoided by giving each different route a different sub-stop area along the platform.

Impact on mixed traffic congestion

One of the main reasons traffic authorities decide to shift to trunk and feeder bus route systems is to reduce adverse impacts of bus traffic on mixed traffic. If direct services require more buses to accommodate the same passengers on congested trunk corridors, then the BRT system itself is likely to require more right-of-way to accommodate this higher bus volume to avoid congestion. This consumption of space may adversely impact the right-of-way available to mixed traffic, or to non-motorised facilities.

Customer friendliness and quality of service

Direct services may also tend to increase system complexity and therefore reduce a customer's understanding of the system. Since the number of routes may proliferate with direct services, the system map tends to look less like a metro system with clearly defined trunk corridors. Instead, the system can appear as a complex web that may only be understood by regular customers. In most systems with direct services, system maps are not even provided at stations or within vehicles. Thus, occasional customers are not able to form a "mental map" of the system as clearly as a system with a straight-forward set of trunk corridors. The net effect of this complexity can be a substantial barrier to entry for discretionary riders and others who do not invest the time in learning the system.

Direct services have also traditionally delivered a lower level of service quality. The lack of off-board fare collection, formal stations, and aesthetically pleasing infrastructure has meant that these systems are perceived more as bus systems rather than mass transit systems. However, there is likely no reason that a system utilising direct services could not be built to the same quality standards of a trunk-feeder system.

7.2.2.3 Direct services in a closed system

Most direct services have historically tended to utilise an "open" system business structure. Systems such as São Paulo's Interligado and Seoul's busways have been able to reap the benefits of exclusive busway operation while reducing transfers for customers. These open systems have permitted improved operational performance without completely reforming the business structure of existing operators. However, inadequacies in station and associated operational design have often led to busway congestion and slower travel times for customers.

By contrast, a relatively new concept is operating direct services within a closed system. In this case, the numbers and types of vehicles are closely controlled by the regulatory agency or system management company. The bunching of vehicles, which tends to occur with direct services in open systems, can be avoided through appropriately sized infrastructure and closely controlled operations.

Although existing systems with direct services have tended to deliver lower-quality standards than trunk-feeder systems, there is no reason why the same amenity features cannot be given to direct services. For example, most systems with direct services require on-board fare collection and fare verification. This practice can considerably delay dwell times at stations. Direct services within a closed system could employ off-board fare collection on high-demand corridors and on-board fare collection with electronic ticketing in low-demand corridors, where there are fewer boarding passengers to cause stopping delays. Such systems can use pre-paid boarding stations even off the trunk corridor in locations like train stations or shopping malls, where a large number of passengers are likely to be boarding and alighting. The proposed Guangzhou system plans three such off-corridor BRT stations as part of the first phase.

This dual fare system would require the additional cost of having fare collection and fare verification equipment both on the vehicles and also in the stations. This type of system would also require special vehicles with doors on both sides.

Normally, for direct services in a closed system, a determination is made as to which existing bus routes will be brought under the management authority of the new BRT system in order to operate within the new system. This decision-making process will also determine which existing bus routes will continue to operate in mixed traffic lanes, and thus operate outside of the management structure of the new BRT system. This determination is typically made based on the frequency of buses on the particular route in the corridor, and the percentage of the route overlap on the corridor. If too few routes are brought into the new BRT system, the buses outside the BRT system will contribute significantly to mixed traffic congestion. Once this determination is made, all of the buses operating on those routes will have to be replaced with "flexible vehicles" (*i.e.,* vehicles with doorways on two sides).

The pre-paid boarding stations and physically separated busways are then only constructed on the trunk corridors where traffic congestion is a problem and where high volumes of boarding and alighting passengers justify the cost of pre-paid boarding stations.

While this new concept is yet to be fully implemented, the developers of the proposed Ahmedabad and Guangzhou BRT systems are investigating the possibility of a closed system operated through direct services. The idea is to help as many passengers as possible to make their entire trip without transferring, and to remove the need for constructing transfer terminals. These systems also mitigate the need for fundamental changes in the route licensing structure and concession agreements with existing operators.

Fig. 7.18
Vehicles operating on the proposed BRT system in Guangzhou will move directly from an exclusive busway to feeder routes, and thus greatly reduce the need for passenger transfers.
Image courtesy of ITDP

However, the lack of structural reform can also be an impediment to higher-quality services.

Figure 7.18 provides a map of the proposed Guangzhou system. All the existing bus routes illustrated in Figure 7.18 will be allowed to operate along the BRT trunk corridor. The physically segregated busways and pre-paid boarding stations will only be built on the trunk corridor illustrated in green.

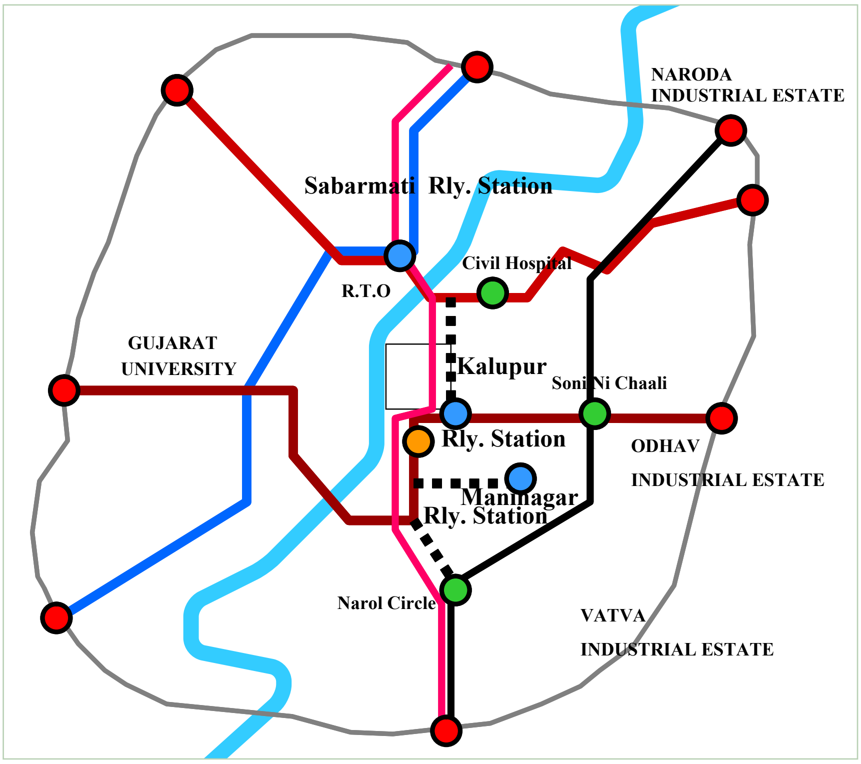
Figure 7.19 outlines the concept being examined for Ahmedabad. In parts of the city centre, the roadway is narrow and volumes of bicycles and motorcycles are quite high, and thus making fully segregated busways politically difficult in Phase I. Nevertheless, even in some areas without segregated busways, pre-paid boarding stations are being recommended anyway due to high passenger volumes. The flexible vehicle concept makes it possible to use these measures only where they are required.

While this operating model has many advantages, there are three main disadvantages of direct services within a closed system:

- Larger vehicle fleet requirement compared to a trunk-feeder system;
- Longer average waiting times if the shift to the new system is accompanied by the user of higher-capacity “flexible vehicles” operating at lower service frequencies;
- Less kilometres of segregated busways means that the system seems less “metro-like” in appearance.

However, direct services within a closed system could be a very appropriate solution in many circumstances, especially when there is much advantage to be gained from avoiding customer transfers.

Fig. 7.19
The flexibility of direct services matches the realities of the restricted right-of-way space in Ahmedabad. Vehicles on the proposed BRT system will move directly between segregated busways and mixed traffic lanes.
Image courtesy of ITDP and CEPT



7.2.3 Mix of trunk-feeder services and direct services

Trunk-feeder services and direct services are not mutually exclusive. A system developer could elect to use different services in different sectors of the city, depending on the local circumstances. In areas that give way to low-density residential plots, then a trunk-feeder service can be employed. In areas with less variability in corridor population density, then direct services could be employed.

In some ways, Curitiba has implemented a system that features aspects of both trunk-feeder services and direct services. Curitiba's "Rede Integrada de Transporte" (RIT), *Integrated Transport Network*, encompasses a range of vehicle and route types (Figure 7.20). Curitiba currently operates trunk-feeder routes in five major corridors of the city, and a sixth corridor is currently being planned. The red-coloured vehicles operating on the exclusive busways are known as "Express Buses".

At the same time, Curitiba also operates several other types of services that directly link some areas to the city centre without needing to first travel to a trunk corridor. A "Rapid Bus" is a silver coloured vehicle that connects major destinations with few stops in between; these routes are known as "Direct Lines". These buses operate in mixed traffic lanes but also connect passengers to the trunk corridors. Curitiba also operates "Interdistrict Lines" that connect neighbourhoods through direct routes without having to travel first to the city centre. These green vehicles provide a time-savings service by avoiding a significant detour for passengers wishing to travel from one residential neighbourhood to another. Curitiba's orange feeder buses then connect individual neighbourhoods to terminal sites where passengers can transfer to the other types of services.

Within the RIT system, passengers are able to make transfers without additional payment. Curitiba also operates conventional bus services (yellow-coloured buses) as well as specialised services in mini-buses (white-coloured buses). Some of these specialised services include:

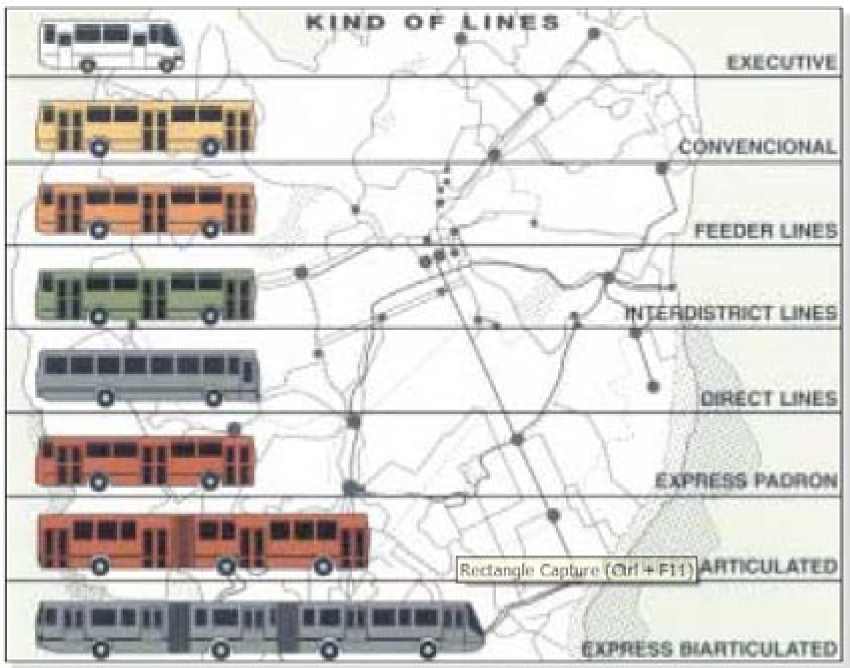
- *Inter-hospital services* – Provides direct services between the city's different hospitals;
- *Tourist services* – Provides services to popular tourist destinations;
- *City centre services* – Provides services to various destinations within the city centre area.

Curitiba also provides an excellent example of how the colour-coding of the buses can help facilitate better system clarity for customers.

The Curitiba does not strictly utilise any examples of direct services since none of the non-express buses enter the exclusive busways. All of the "Inter-district" and "Direct" lines essentially just utilise mixed-traffic lanes. However, these direct express lines operate outside the Curitiba busway only because Curitiba's system did not provide the passing lanes at station stops that are needed to accommodate express bus services. One major trunk corridor in Curitiba is currently being reconstructed to have passing lanes, and in this corridor the direct express services will be brought inside the busway. The intent of these services is quite similar to that of direct services: To provide direct routes between destination pairs that are not covered by the trunk-line services.

The advantages of the Curitiba approach are the flexibility it allows planners to match different urban and demographic conditions. The main disadvantage of this tiered approach is the relative complexity it presents to the customer, and especially to occasional users and new users. Figure 7.21 provides a system map with just Curitiba's trunk routes and a system map with direct and inter-district routes. While the left map is fairly readily understandable, the right map requires a bit more of a studied view. As opposed to a metro-like approach, such as Bogotá, Curitiba's system structure is perhaps less immediately understandable to an outsider.

Fig. 7.20
Curitiba attempts to maximise system efficiency by utilising a wide-range of vehicle and routing types.
Image courtesy of the Municipality of Curitiba



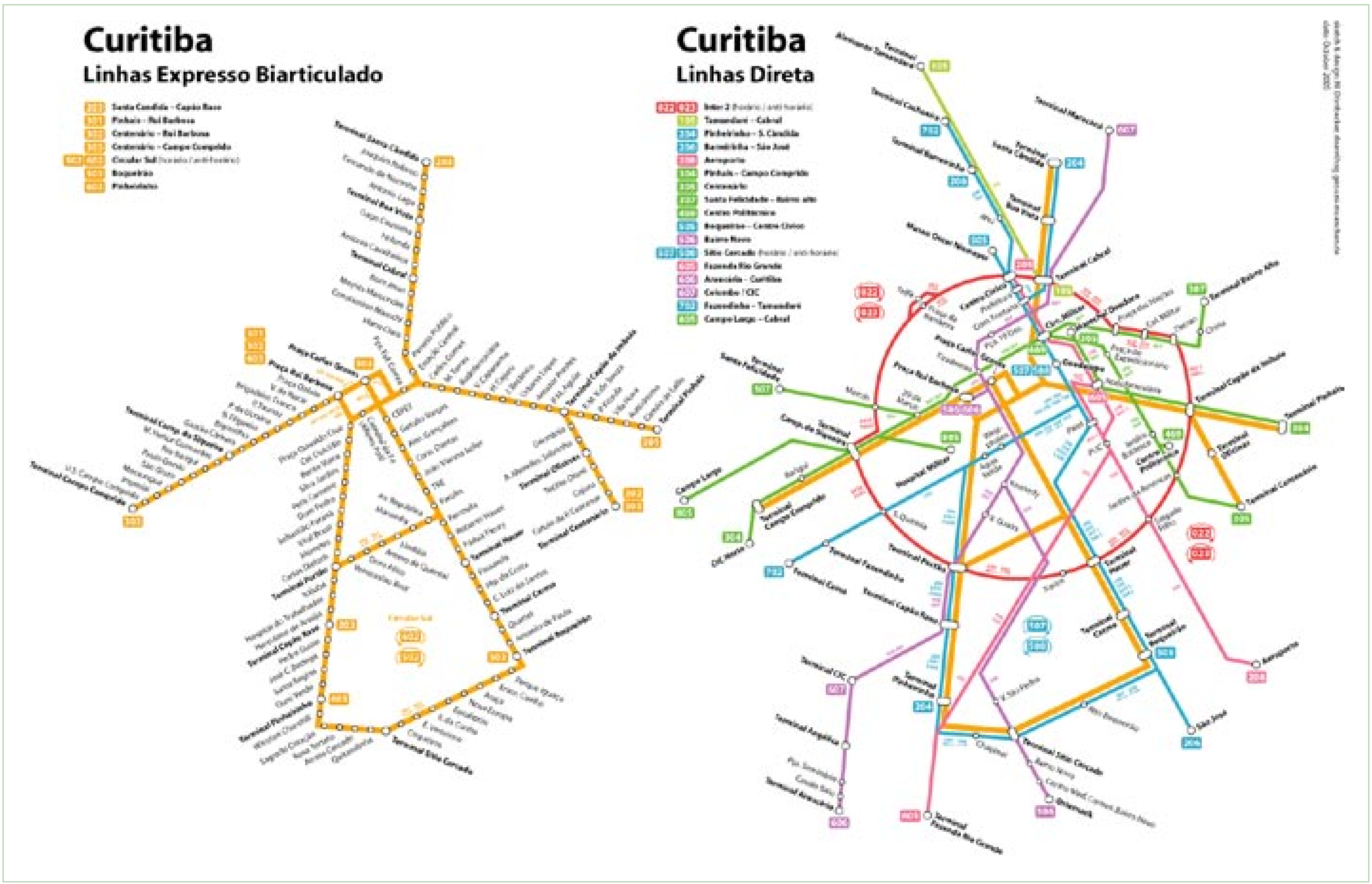


Fig. 7.21
Curitiba's BRT route map. The advantage of Curitiba's system is its high flexibility, but it can appear somewhat complicated to customers.
Image courtesy of the Municipality of Curitiba

7.2.4 Decision framework

"It is the framework which changes with each new technology and not just the picture within the frame."

—Marshall McLuhan, educator and social reformer, 1911–1980

Neither trunk-feeder services nor direct services are inherently a correct or incorrect design option. Either of these options can be effective in the right circumstances. This section discusses some of the factors that can help determine the optimum choice. The best solution will match the local distribution of origins and destinations and the local demographic characteristics.

Further, a system can change from one service type to another as conditions also change. In many cases, direct service BRT systems have been a transitional phase to a trunk and feeder system. Both Bogotá and Curitiba essentially operated direct services prior to their transition to trunk-feeder services. Curitiba shifted its bus routes to a trunk-feeder system in the early 1960s, and only built exclusive busways in the 1970s. In São Paulo, while there have been problems of implementation due to resistance from bus companies, there are detailed plans for shifting all the bus routes on major arterials from direct services to trunk-feeder services. While some of the current corridors have exclusive bus lanes, some of them do not. São Paulo plans to build free transfer facilities at key locations.

Table 7.1: Comparison of trunk-feeder services and direct services

Factor	Trunk-feeder services in closed system	Direct services in open system	Direct services in closed system
Travel time	Time penalty incurred for requiring transfer, but speed and capacity along the trunk busway is maximised	Time saved in avoiding transfers, but "bunching" of vehicles along busway will increase travel time	Allows BRT authority to control busway congestion while also gaining the time savings benefits from fewer transfers
Operational efficiency	Matches supply and demand very closely; produces high efficiency even when there are significant variances in population density between corridors and residential areas	Compromise between high-demand areas and low-demand areas may reduce overall efficiency; however, gains are realised if route distance is short	Compromise between high-demand areas and low-demand areas may reduce overall efficiency; however, gains are realised if route distance is short
Infrastructure	Requires construction of terminals and intermediate transfer facilities	Avoids cost of terminals but may require more costly stations	Avoids costs of terminals
Vehicle types	Trunk routes typically restricted to large vehicles; feeder routes typically employ standard sized buses or smaller	Often little standardisation of vehicles; vehicles may require doorways on both sides	BRT authority can standardise the vehicles; vehicles must be capable of both on and off busway operation and thus may require doorways on both sides
Capacity	High passenger flow rates can be handled efficiently with trunk-feeder services	The bunching of vehicles and on-board fare payment inhibit system capacity	Capacity will be somewhat lower than for trunk-feeder systems as vehicle sizes will be somewhat smaller
System image / customer friendliness	Metro-like route structure makes for customer-friendly system	Lack of clear route maps and plethora of routes can create customer confusion	Potentially more complex than a trunk-feeder system but more organised than an open system

7.2.4.1 Summary comparison of services

Table 7.1 provides a summary comparison of the advantages and disadvantages of each service type.

7.2.4.2 Optimum conditions for each service type

This section has detailed the advantages and disadvantages of trunk-feeder and direct services. The complex list of variables involved is not likely to be easily analysed through a cost-benefit analysis. Instead, system developers may need to make qualitative judgements based on their own local conditions. This final subsection outlines a few general decision-making rules that may help facilitate the best fit with the local situation.

A trunk-feeder service within a closed system is likely to be effective under the following conditions:

- Main corridors have relatively high demand;
- Population densities between different areas of the city are significantly different;
- Distances between the city centre and the feeder areas is relatively far, *e.g.*, over 10 kilometres in length.

In general, a direct service within an open system is not recommended. However, such a system could be a transitional step to a more formalised closed system.

A direct service within a closed system is likely to effective under the following conditions:

- Main corridors have relatively low demand;
- Population densities between different areas of the city are not significantly different;
- Distances between the city centre and feeder areas are relatively short, *e.g.*, less than 10 kilometres.

However, as has been stressed throughout this section, there is no single correct option; the best service type depends significantly on local circumstances. System developers may also elect to develop a mix of both trunk-feeder routes and direct service routes.

7.3 Route design

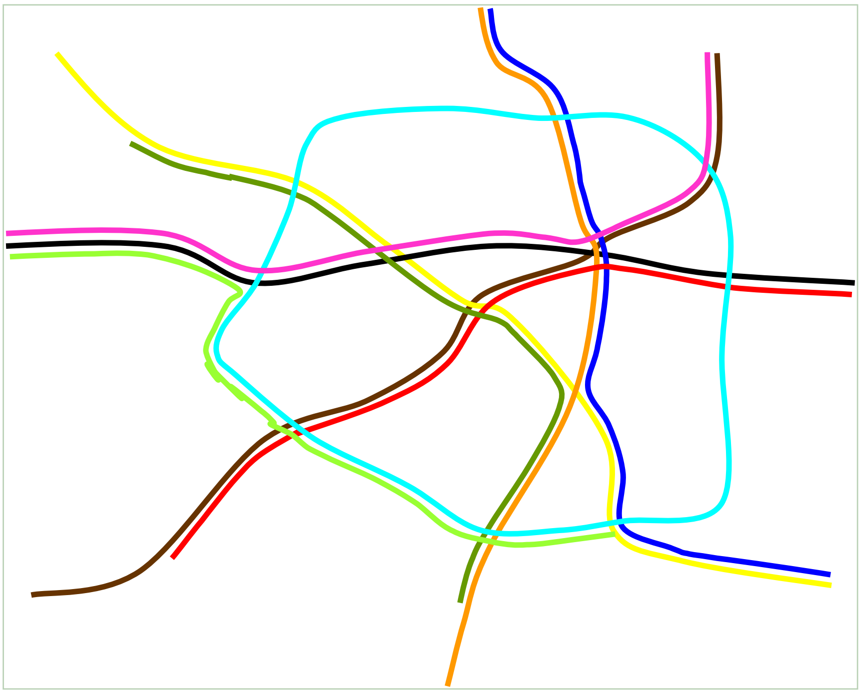
"A route differs from a road not only because it is solely intended for vehicles, but also because it is merely a line that connects one point with another. A route has no meaning in itself; its meaning derives entirely from the two points that it connects. A road is a tribute to space. Every stretch of road has meaning in itself and invites us to stop."

—Milan Kundera, novelist, 1929–

The choice of the BRT corridors only provides a macro-level view of where a system will operate. Within a given set of corridors, vehicles will serve particular routes. The route selection process within and between corridors determines many operational characteristics that will directly impact customer travel times and convenience.

No system will likely be able to provide a route network that caters to every possible permutation of origins and destinations. Transfers between routes will be inevitable for some origin-destination combinations. However, a well-designed routing system can optimise travel times and convenience for the largest number of journeys, and significantly reduce operating costs.

Fig. 7.22
BRT and the synergies of route permutations



The relative flexibility of BRT in comparison to other public transport options means that routes and services can be tailored quite closely to customer needs. The system can be designed to minimise travel times for the greatest number of passengers. Routing options, such as local, limited-stop, and express services, permit an array of permutations that maximise system efficiency and minimise travel times for customers. Both passengers and operators can benefit from adjusting public transport services to more closely match existing demand. An effective route network can be achieved through the following design principles:

1. Minimising the need for transfers through efficient routing permutations;
2. Providing local, limited-stop, and express services within the BRT system;
3. Shortening some routes along a corridor to focus on high-demand sections.

Customers typically prefer to have choices and options. Providing alternative routing options serves several objectives, including good customer service, reduced travel times, and increased system capacity.

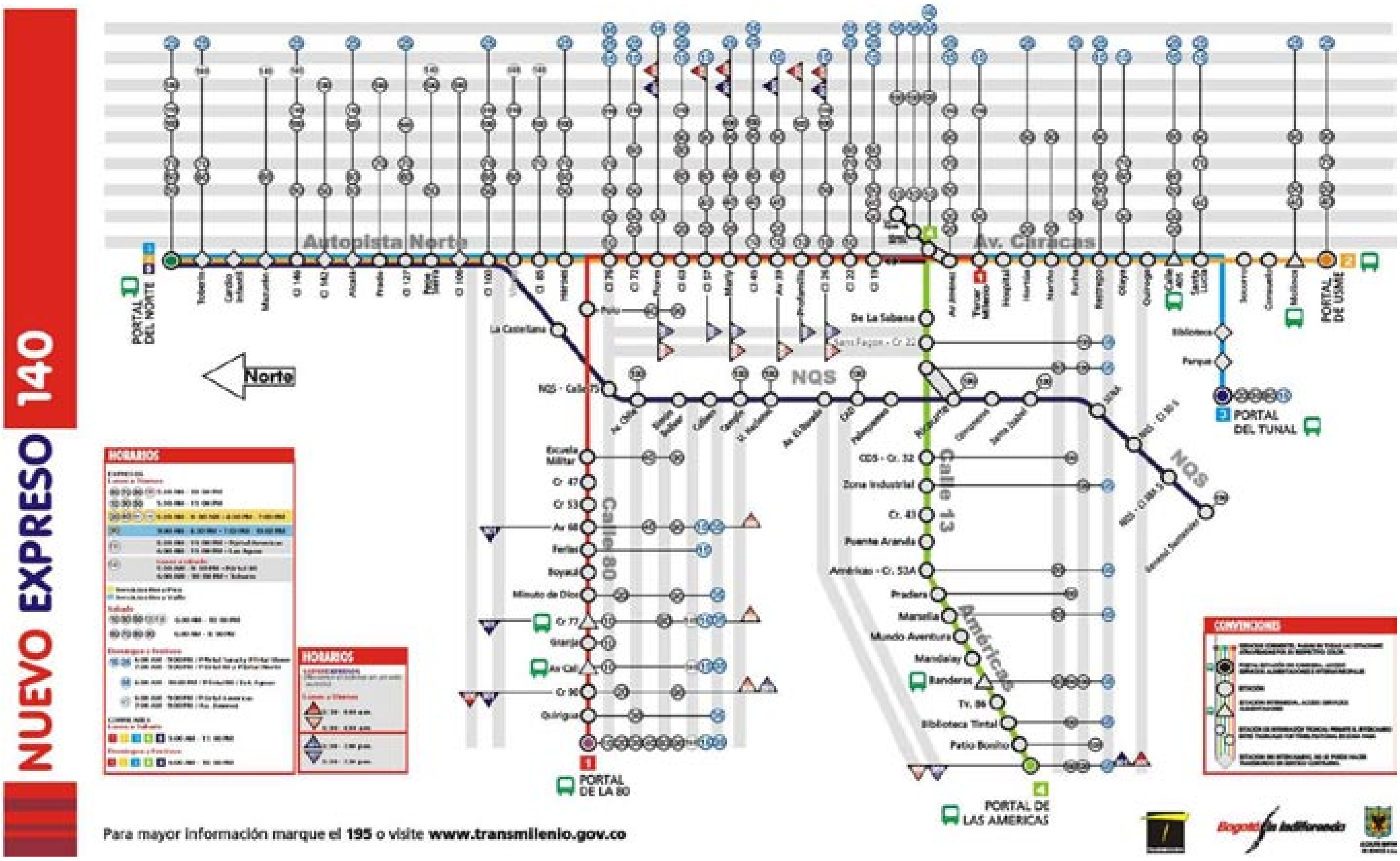
7.3.1 Route network

"A system is a network of interdependent components that work together to try to accomplish the aim of the system. A system must have an aim. Without the aim, there is no system."

—W. Edwards Deming, statistician, 1900–1993

BRT is unique as a public transport system in terms of its flexibility with routing options. The ability of rubber-tyred vehicles to change lanes and directions at will allows any number of potential routing permutations. By contrast, rail-based vehicles are limited to set tracks and can only make line switches in low-frequency circumstances.

The most immediate advantage of multiple route permutations is the avoidance of transfers for passengers and the subsequent savings in travel times. If a passenger has several route options from which to choose, then the likelihood of a required transfer is lessened. Additionally, more efficient passenger movements also equate to more efficient system operations. Further, as the need for transfers is minimised or even eliminated, the cost implications for complex



transfer stations are reduced. Figure 7.22 is an illustration of the type of routing options possible with BRT systems.

Bogotá's TransMilenio system has been one of the most successful BRT systems to exploit the power of multiple route permutations. Customers at a single station may have as many as ten different routes from which to choose, including local and limited-stop services.

While the customer and operational benefits of the Bogotá routing permutations are clear, there is one potential drawback in terms of system complexity. As the number of routing permutations increase, the operational complexity to manage such a system becomes significant. Bogotá's TransMilenio system benefits from satellite location technology and a sophisticated control centre to ensure the vehicle movements operate smoothly. Without such technology, it is unlikely that a system of this complexity level could function well.

Bogotá's routing complexity can also be somewhat bewildering to new and occasional users. Due to the large number of route permutations, Bogotá's system map is fairly complex (Figure 7.23). Rather than showing different coloured lines for each route, Bogotá must list the route numbers that service each stop. A map user must essentially follow the numbers through the

Fig. 7.23

The Bogotá TransMilenio system offers a large number of route permutations to maximize customer convenience, but the end result can be a fairly complex route map.

Image courtesy of TransMilenio SA

Fig. 7.24

The complexities of the TransMilenio routing system can be a bit perplexing to customers.

Photo by Carlos F. Pardo

system to determine which route is most appropriate for their journey (Figure 7.24). Given the number of routes in the system, if TransMilenio attempted to fully colour-code its maps, then the ensuing tangle of lines would likely also confuse customers. Further, there would not be a sufficient number of distinguishable colours to show the various TransMilenio routes in such a map.

Despite such complexities, the minimisation of transfers and options given to customers makes systems with multiple routing permutations quite convenient to passengers.

More recently, TransMilenio has divided its system into coloured zones (Figure 7.25). A passenger will identify the destination by relating it to zonal colour. In term, the passenger can consult individual routing maps to determine which route option within their zonal colour will be the most efficient. As has been the case with TransMilenio, a city with a complex routing structure will likely experiment with various display options to determine which provides the customer information in the most user-friendly manner.

7.3.2 Transfers

The impact of transfers on ridership cannot be underestimated. Transfers are often one of the main reasons discretionary riders will elect not to use a system. Further, if the transfers involve any form of physical hardship, such as stairs, tunnels, or exposure to rain, cold, or heat, then the system's acceptability is even more compromised.

7.3.2.1 Types of transfers

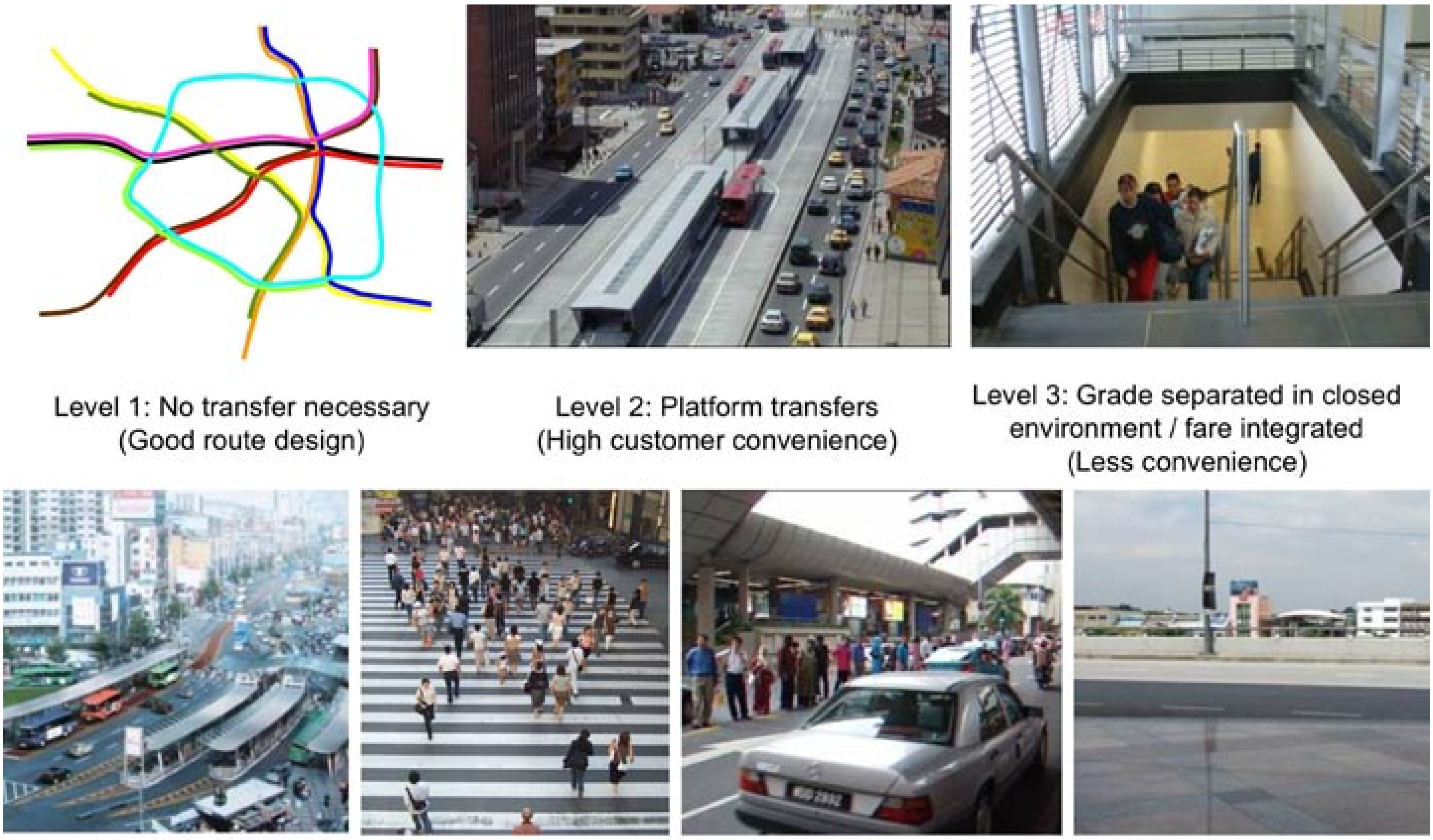
Not all transfers are created equally. On one extreme are transfers involving lengthy walks across intersections and other obstacles while being unprotected from rain and wind. At the other extreme are transfers involving a simple few metre walk across a comfortable, safe, and weather-protected platform. Which of these two types of transfers are possible depends much on the infrastructure design and the route design.

In reality, there is a spectrum of possible of transfer arrangements. Figure 7.26 illustrates the different types of transfer options.

The most desirable option is obviously to avoid transfers altogether for the vast majority of customers. Thus, level 1 in Figure 7.26 underscores the importance of utilising good system and route design to eliminate the need for transfers. Level 2 is recognition that some transfers may be necessary but that the use of multiple sub-stops at stations can permit customer-friendly platform transfers.

As the type of transfers become more difficult beyond level 2 transfers, then the system will likely begin losing some discretionary customers (*i.e.,* customers who have other mobility options such as private vehicles). A level 3 transfer implies that a customer must physically walk from one corridor to another (typically around an intersection area). However, in level 3 the walk is within a closed and protected environment, such as a pedestrian overpass or a tunnel. Further, in level 3, the transfer still occurs without

Fig. 7.25
With an ever-growing number of routes, the most recent TransMilenio system map has foregone showing individual routes and instead divides the system into several colour-coded zones.
Image courtesy of TransMilenio SA.



Level 1: No transfer necessary (Good route design)

Level 2: Platform transfers (High customer convenience)

Level 3: Grade separated in closed environment / fare integrated (Less convenience)

Level 4: Grade separated in open environment / fare integrated (Less convenience)

Level 5: Grade separated in open environment / fare compatible (Inconvienent)

Level 6: Grade separated and fare separated (Inconvienent)

Level 7: Physical barriers to transfer and fare separated (Poor customer service)

Fig. 7.26
Types of transfers

any penalty payment or the need to go through another fare verification process.

With levels 4 and 5, the customer must make a transfer in an "open" environment, meaning that they must physically leave the confines of one system and then enter another. There are two clear disadvantages to this approach. First, the customer will likely have to cross an intersection and also undertake the inconvenience of walking up and down stairways or escalators. A customer with a small child or with several shopping bags may find the physical nature of this transfer prohibitively difficult. Second, customers must re-verify their fare medium since they are entering from outside the system. The re-verification process can involve several possible delays and queues.

The Seoul integrated transit system is an example of a type 4 transfer. Customers entering a bus must swipe their smart card with an on-board card reader. The same customers must remember to swipe their cards again upon exiting. Then, if a person wishes to continue the journey using the city's metro system, the card is swiped upon entering and exiting the metro system. In each case, customers must remember to swipe their smart card as well as incur a delay due to a queue at a card reader. However, the Seoul system is fully "fare integrated". With a fare integrated system the total fare charged to the customer is based on the total distance travelled. A customer is not charged a new "entry" fee into the system. In Seoul, the smart card technology allows a quantity to be deducted primarily on a distance basis. However, the distance covered when using the metro rail system is charged at a higher rate than when using the BRT system.

The difference between a type 4 transfer and a type 5 transfer is the difference between "fare integration" and "fare compatibility". Whereas fare integration allows a customer to avoid paying an additional entry fee into the second system, fare compatibility does not. With fare compatibility, a customer can use the same fare medium, such as the same smart card, but must essentially pay for an entirely new fare when entering the second system. Fare compatibility does not imply that there is any distance-based consideration in determining the fare for a journey that encompasses two different systems. For example, in Tokyo, there are two different metro rail systems: 1. Tokyo Metro; and 2. Toei Metro. It is possible to purchase a smart card that can be utilised on both systems. However, when transferring from one system to another, a customer must effectively pay two separate fares. Thus, fare compatibility allows some convenience in terms of using a single fare payment method, but the fares are not fully integrated and this lack of integration means that customers will likely pay more.

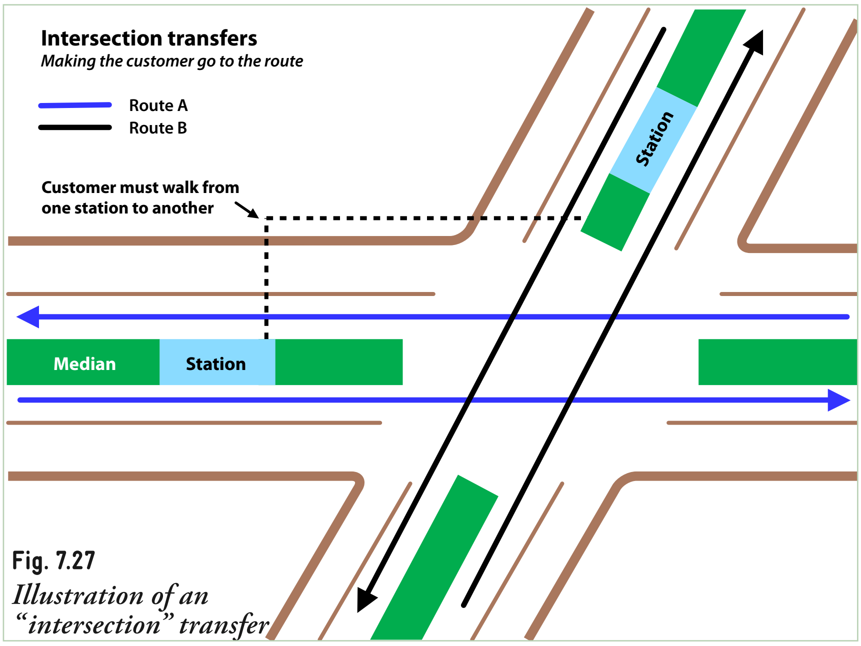


Fig. 7.27
Illustration of an "intersection" transfer

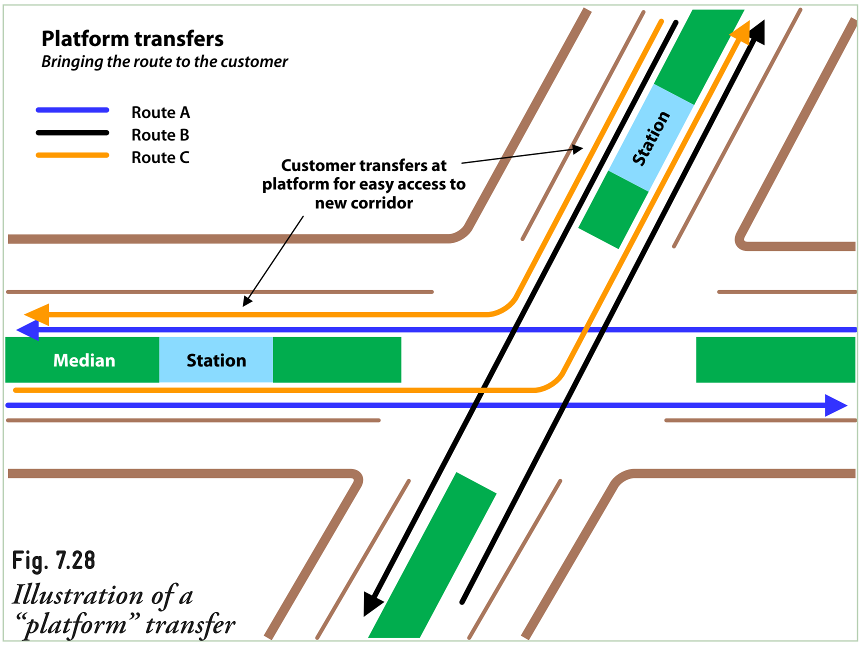


Fig. 7.28
Illustration of a "platform" transfer

By the time that one reaches transfer levels 6 and 7, any discretionary customers will generally opt not to utilise the public transport system. At levels 6 and 7, there is neither physical nor tariff integration between different systems. Customers must not only pay twice but also must endure a difficult physical environment to walk from one system to another. Level 7 is the most difficult with actual physical barriers making transfers at the same station area almost impossible. For example, in Kuala Lumpur the KL Sentral station hosts both PUTRA LRT operations and the KL Monorail operations. However, to walk from one to another implies a 20 minute walk through multiple changes in grade and an unpleasant parking lot environment. Likewise, changing from an intersecting PUTRA LRT line and a STAR LRT line in Kuala Lumpur is also a challenging experience. The three different rail systems in Kuala Lumper were not designed with much consideration for customer convenience in transfers (see levels 6 and 7 in Figure 7.26).

7.3.2.2 Facilitating platform transfers

As indicated from the options given in Figure 7.26, if a transfer is necessary, then a platform transfer in a safe and pleasant closed environment is the preferred option. A platform transfer essentially brings the vehicle (and the route) to the customer. By contrast, an intersection transfer means that a customer is traversing the distance of an intersection to access the intersecting route. While the physical hardship of an intersection transfer can be eased through a pedestrian tunnel or overpass, it is always less desirable than a simple platform transfer. In this case, the system is forcing the customer to go to the route, rather than the other way around.

To achieve a platform transfer, an intersecting corridor must be connected by way of the routing system. Figures 7.27 and 7.28 illustrate the routing circumstances that either force an intersection transfer or permit a platform transfer.

Thus, the simple addition of a new route in Figure 7.28 provides much transfer convenience to the customer.

7.3.3 Local, limited stop, and express services

7.3.3.1 Local services

The most basic type of public transport service along a corridor is typically known as "local service". This term refers to stops being made at each of the major origins and destinations along a route. "Local services" imply that no stops are skipped along a route. Thus, while local services provide the most complete route coverage along a corridor, such services also result in the longest travel times.

Single track metro systems and simple, single lane BRT systems like TransJakarta and RIT Curitiba typically have few options but to operate only local services. There are no provisions within the narrow infrastructure of these systems for vehicles to pass one another.

In comparison to conventional bus services, the local services of a BRT system are considerably more efficient. In many developing-nation cities, public transport services operate on a "hail and ride" basis. The bus will effectively stop whenever hailed by a customer, whether the customer is at a bus shelter or not. The bus may stop every few metres if requested. This situation is particularly true when operator income is based on the number of passengers carried. While this practice will reduce walking distances to access a bus, the net effect of all passengers controlling stopping location greatly increases overall travel time for everyone. For minibuses, because there are fewer passengers, the number of such stops is minimised, and once the minibus is full it may not stop at all. This can often lead to very fast travel speeds, but it can also mean that some passengers during peak periods can wait a long time until a minibus is willing to stop, and the service is highly unpredictable.

By contrast, BRT stations only alight and board passengers at designated stations. Further these stations are separated by enough distance to minimise stop times while at the same time are close enough to be accessed by most persons in the area. A typical range of distances is between 300 metres and 700 metres. By avoiding short stopping distances, the overall travel time is reduced due to higher average vehicle velocities.

The location of BRT stations will follow from the origin and destination modelling conducted earlier. Major destinations such as commercial centres, educational institutions, and large employers will all influence the location. Additionally, an array of other factors, such as road configuration, will also play a determinant role in choosing a cost-effective location that best serves the customer.

7.3.3.2 Limited-stop services

Single lane BRT systems with only local services have significant disadvantages. Most importantly, at high passenger volumes, they have much lower capacity and speed. Typically, the vast majority of passengers will get on and off at a few major stations. A few passengers, however, will get off at less used stations. For many passengers, stopping at each intermediate station adds significantly to the overall travel time with relatively little commercial benefit to the system operators. Thus, both passengers and operators can benefit from the provision of services that skip intermediate stops.

BRT's relative flexibility means that "limited-stop services" or "skipped-stop services" can be accommodated. The number of station stops to be skipped depends on the demand profile. Major station areas with the largest customer flows may be the most logical stops retained in a limited-stop service. However, the system can employ multiple limited-stop routes in order to ensure travel times are minimised for the largest number of customers. Thus, limited-stop routes can differ by the stations served as well as by the number of stations skipped by the service. Some routes may skip 3 or 4 stations while other routes may skip double that number.

Well-designed stations can permit customers to transfer from a local service to a limited-stop service. Thus, even if a customer does not reside near a limited-stop station, he or she can transfer to a more rapid service after just a few stops in a local-service vehicle. In some instances, customers may find it advantageous to go beyond their desired stop in a limited-stop vehicle and then return a few stations by way of a local service. The principal idea is to give the maximum flexibility to the customer in order to reach the destination in the most convenient manner.


Fig. 7.29 and 7.30
Passing lanes at stations as practiced in Bogotá (left photo) and São Paulo (right photo) allow for the provision of express and limited stop services, which deliver significant travel time savings to customers.
Left photo courtesy of TransMilenio SA
Right photo courtesy of Booz Allen Hamilton

The main advantages of limited-stop and express services are thus:

- Time savings for vehicles and passengers using limited-stop services;
- Reduction of saturation (*i.e.,* congestion) at stations that have been skipped, meaning smaller stations can be built in some locations
- Increase in overall capacity of system.

However, these services also introduce some challenges for system managers:

- Some passengers may experience increased waiting times; as more lines are added, the frequency on each line will be reduced;
- More complicated system from both the standpoints of system management and customer understandability;
- Requirement of passing lanes at stations.

While limited-stop services do provide much amenity value to customers, these services do introduce greater complexity to the management of the system. The coordination of vehicles on the same corridor with different travel characteristics can be a challenge. Limited-stop services are thus best implemented in conjunction with vehicle tracking technology that permits a central control team to oversee and direct vehicle movements.

The provision of limited-stop services also implies particular infrastructure requirements. In order to skip stops, the limited-stop vehicles must be able to pass intermediate stations. Thus, sufficient road space must be available for either a second set of exclusive busway lanes or the provision of a passing lane at by-passed stations (Figures 7.29 and 7.30). These requirements mean that cities employing limited-stop services will incur greater system complexity and higher infrastructure costs. Chapter 8 (*System capacity and speed*) discusses how passing lanes can be fitted for even relatively narrow right of ways.

Some cities with single lane busways also utilise limited stop and express services. The vehicles pass by way of the opposing lane. The Quito Trolé and the Beijing Qinghua Dong Road busway both make use of this technique. In general, though, overtaking by way of the opposite lane is not recommended. There are obvious safety issues involved with such an approach (Figure 7.31). The risk of a head-on collision between rapidly approaching vehicles is a real possibility. Further, this arrangement can only be done in conjunction with side-aligned stations, which create other types of operational problems.

Another technique is to time services so that limited- stop or express services only catch up with the local services at the terminal point of a route. Thus, an express service may begin ten minutes behind a local service, and this starting time difference ensures that the express service does not overtake the local service. This technique is quite commonly applied to urban rail systems in Japan, such as the Hankyu service in Osaka. The applicability to BRT, though, is likely to be limited. Unless a corridor is relatively short, the starting time difference between local and express vehicles would have to be quite significant (*e.g.,* 10 minutes). This difference is probably too large to accommodate the required vehicle frequencies for BRT systems in the high-capacity corridors of many developing-nation cities.

7.3.3.3 Express services

Another type of limited-stop service is known as an "express service". Express services skip all stations between a peripheral area and a central core area. Thus, express services are an extreme form of limited-stop service.

Express services function quite well when the origin of the trip is a high-demand area that is some distance from the city centre. If population densities are such that vehicles reach capacity at peripheral areas, then it can be efficient to transport these passengers directly to central locations. In many cases, the trip origin for an express service will be a transfer terminal where demand from numerous feeder services has been consolidated.

The reduced travel time of express services can be a major enticement to curb the growth of private motorised vehicles in the city's periphery. In many developing cities, low-income communities are often located at such peripheral locations, and thus, the provision of express services can be way of achieving greater equity within a system.

Fig. 7.31
By allowing vehicles to overtake in the opposing lane, there are obvious risks of a serious collision as evidenced in Beijing.
Photo by Lloyd Wright

Express feeder buses can also work well to connect a large residential area a considerable distance from the transfer terminal (Figure 7.32). TransJakarta, for instance, has introduced express non-stop feeder buses from a suburban shopping mall to one of the TransJakarta stations.

7.3.4 Shortened routes

Even within BRT systems that only allow for local stops, it is possible to adjust the service to better meet the demand by having some bus routes turn around before reaching the final terminals. The same corridor can host several routes of varying lengths.

Ideally, the highest-frequency of service will be provided on the highest-density section of the corridor. Thus, rather than operating a route across the entire length of a corridor, the service can focus mostly on the higher-demand portions. A single corridor may be split into two or more routes covering a different portion of the

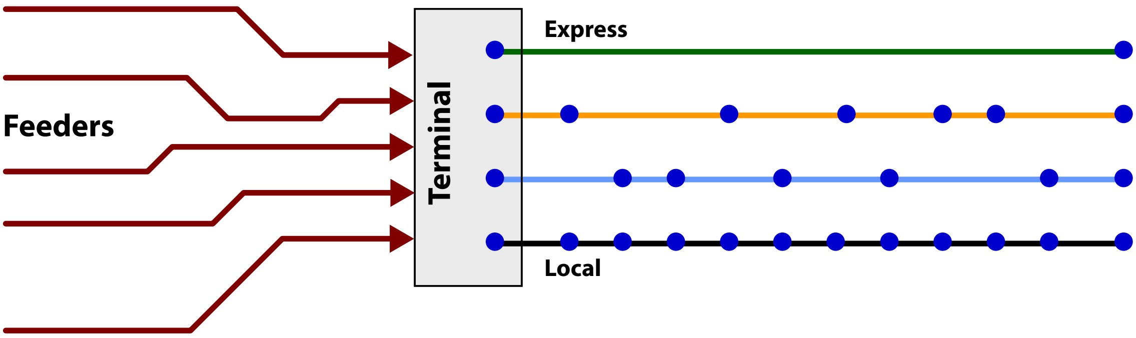
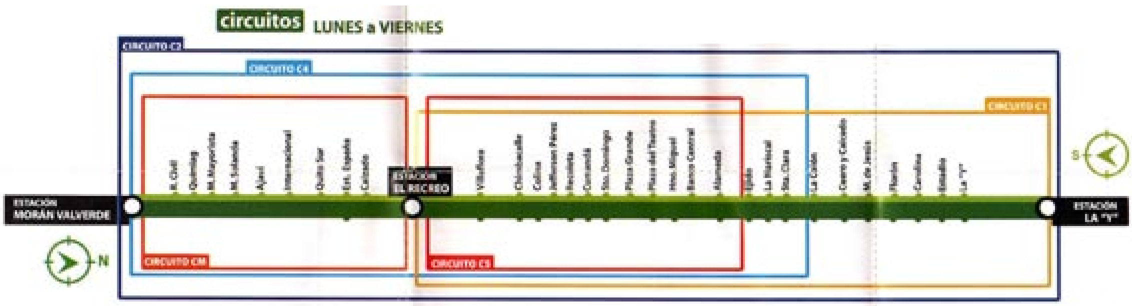


Fig. 7.32
Schematic of feeder lines supporting local and express services from a single terminal.

Fig. 7.33
Quito's Trolebus utilises five different routings in a single corridor.



corridor. The Quito Trolé operates five different routes within a single corridor: 1. A northern route; 2. A central route; 3. A central-southern route; 4. A southern route; and, 5. A route encompassing the entire corridor (Figure 7.33). Thus, in the case of the Quito Trolé, the central portion of the system is served by five routes while the outlying sections are serviced by no more than two routes. An illustrated example of this type of routing for Jakarta's Thamrin-Sudirman corridor is given in Figure 7.34.

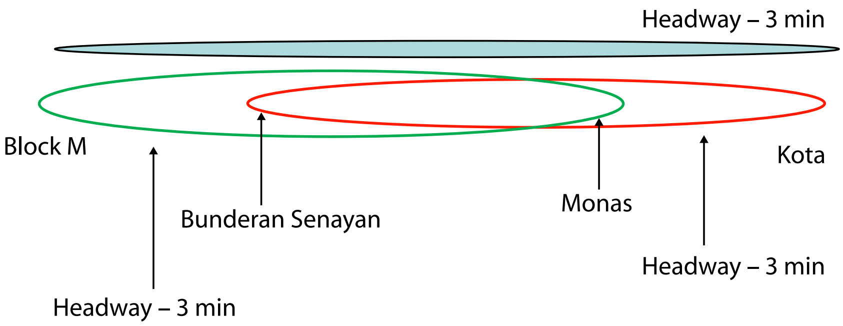


Fig. 7.34
A possible multiple routing along the Thamrin-Sudirman corridor in Jakarta.
Image courtesy of Pedro Szasz

This routing option gives the majority of customers a higher-frequency service. This routing option also results in significantly reducing the number of buses and driver needed to service a given demand along a corridor.

The disadvantages of this approach include:

- Greater complexity in managing the movement of vehicles;
- Lower service frequencies for customers travelling beyond the central area;
- Difficulties in turning vehicles around at a mid-corridor location;
- Customer confusion;
- Potential station crowding at route termination points.

With good planning and control, these problems can be overcome. A central control system can help to control vehicle movements and avoid bunching in a multiple-route situation.

The choice of station to terminate a particular route will determine the ease in turning around the vehicle. In general, mid-corridor directional changes will not have a terminal site available to facilitate turning. Thus, in the ideal case, the street width would accommodate an immediate u-turn at the end of the station. The San Victorino station in Bogotá allows this type of vehicle movement (Figure 7.35). Alternatively, a vehicle could briefly leave the busway and make a turn across an elevated structure (*e.g.*, Quito Trolé) or the vehicle could take a detour through a series of turns around the block. Of course, anytime a vehicle leaves the exclusive busway there is a risk of unforeseen delays due to traffic congestion.

Customers expecting a vehicle to continue to the end of a corridor might be surprised to learn that the vehicle is terminating prior to the final station. While the customer will be able to transfer to the next available vehicle making the full route, such confusion can lessen customer satisfaction. Further, the final station of the shortened route may become crowded with many persons forced into making a transfer. Clear signage, maps, and customer announcements can all help to overcome customer confusion. Likewise, the colour-coding of route signage and vehicles can further reduce uncertainty.

In Quito, both the Trolé and Central Norte lines provide very little information to the

Table 7.2: Service frequency for shortened and full-routes in Jakarta

	No. of vehicles serving station			
Station name	**Senayan**	**Monas**	**No turn**	**Total**
Kota	9		16	25
Monas	9	16	16	41
Bunderan Senayan	9	16	16	41
Blok M		16	16	32

customer regarding the approaching vehicle. Customers using the Trolé system, only have a few moments of time to recognise which route is approaching the station. A small plaque in the windscreen of the bus is the only indication of the route. The sight-line to see this plaque is quite obscured due to the station infrastructure. No pre-announcement is made nor is there any digital display indicating which route is approaching the station. Such lack of customer informational support can cause much stress and confusion amongst passengers.

In general, the shortened route should not be terminated at the highest-demand point in the system. These stations are already stressed by the quantity of passengers and the intensity of customer movements. Further, since these stations tend to be located in the densest portion of the urban area, there are fewer opportunities to efficiently turn around the vehicles. Thus, the route termination / vehicle turning point should be at least one or two stations removed from the busiest station.

This type of route programming will typically reduce overall operational costs by up to 10 percent. In order to accommodate a shortened route option, the planning process should provide sufficient flexibility with regarding:

- Providing places where buses can make u-turns within the BRT system; and,
- Designing the station areas with sufficient extra capacity to allow for service adjustments.

Adequate programming of bus services even within a system of all local services can reduce operational costs by up to 10 percent. The public transport modelling process can help to forecast corridor and station passenger demand, and thus help determine the optimum form of the shortened routes. Through this process, the multiple corridor routes for Jakarta have been determined, as given in Table 7.2.

Box 7.1 summarises the savings the Jakarta routing proposal produces in terms of the size of the required vehicle fleet.

Fig. 7.35
Some vehicles make a u-turn movement in the city centre of Bogotá in order to begin a new route direction.
Photo by Lloyd Wright

7.3.5 Decision factors in route selection

As with corridor selection, the most basic principle for route selection is to focus upon serving the majority of passengers in the most efficient manner possible. Thus, system planners will aim to serve the most common origin-destination pairs in the most rapid and direct manner. This objective particularly implies the avoidance of transfers for the majority of passengers. The basis for this selection therefore is the public transport modelling work that should supersede the route selection.

Beyond the first emphasis on serving the demand profile in the most direct manner, there may be other decision criteria. The physical

Fig. 7.36
A vehicle making a u-turn at the end of a corridor in Curitiba.
Photo courtesy of the Volvo Bus Corporation

Box 7.1: Calculating fleet reduction from shortened routes

Shortened routes focussing on higher-demand central areas will contribute to high operating efficiencies. These efficiency gains will help reduce the number of vehicles required to serve the corridor. The graphic below illustrates the demand profile along the length of a corridor.

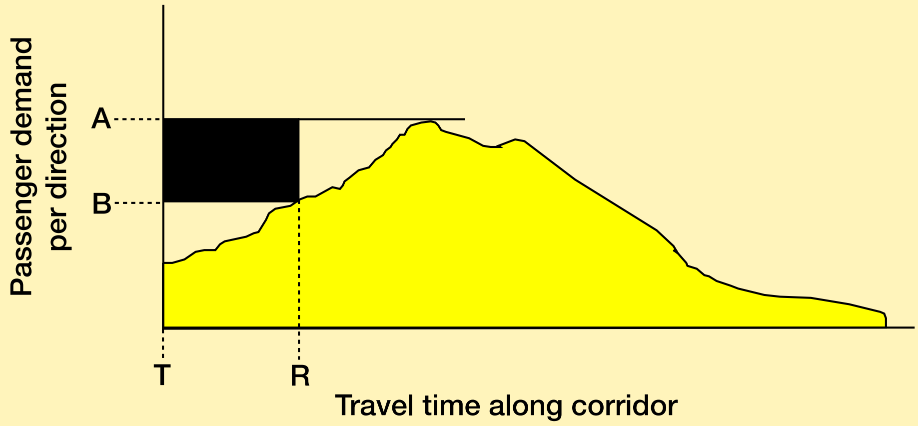


Fig. 7.37
Offering the option of shortened routes along a corridor can help reduce vehicle fleet requirements.
Image courtesy of Pedro Szasz

In the figure above, most of the corridor's demand occurs in the central areas. Under a full corridor route, all vehicles would commence from point T. However, if vehicles were to operate a shortened route beginning from point R, then the number of vehicles required to serve the corridor will be reduced. This fleet reduction is calculated as:

Fleet reduction = [2 * (R – T) * (A – B)] / C

Example:
A = 15,000 passengers/hour
B = 10,000 passengers/hour
R – T = 10 minutes (uni-directional time) = 10/60 hours
C = 150 pas/bus (vehicle capacity)

Fleet reduction = [2 * (10/60) * (15,000 – 10,000)] / 150 = 11 vehicles

nature of the corridors will also affect route selection. In some cases, turning from one corridor to another may be difficult to traffic or physical constraints. Ultimately, the number of route permutations and services added is limited by two factors: 1. Congestion on busway due to number of services; and 2. Confusion amongst customers regarding the overwhelming number of permutations.

As a quick general rule, the first priority for routing efficiency gains is ensuring a transfer-free option is available for customers travelling between any two major corridors that intersect. As a next step, significant efficiency gains can be achieved along any corridor by simply operating one local service and one limited-stop service focussed upon the highest demand stations. This simple division into two services will likely significantly improve the average speed and overall capacity of the system. Adding express services between the main transfer terminal and the city centre would likely be the next line to add. Even if demand is completely uniform, if bus frequency is sufficiently high, this concept can be extended and more express lines can be used, with speed and capacity gains for the system. Figure 7.38 summarises the process of building up an effective route structure.

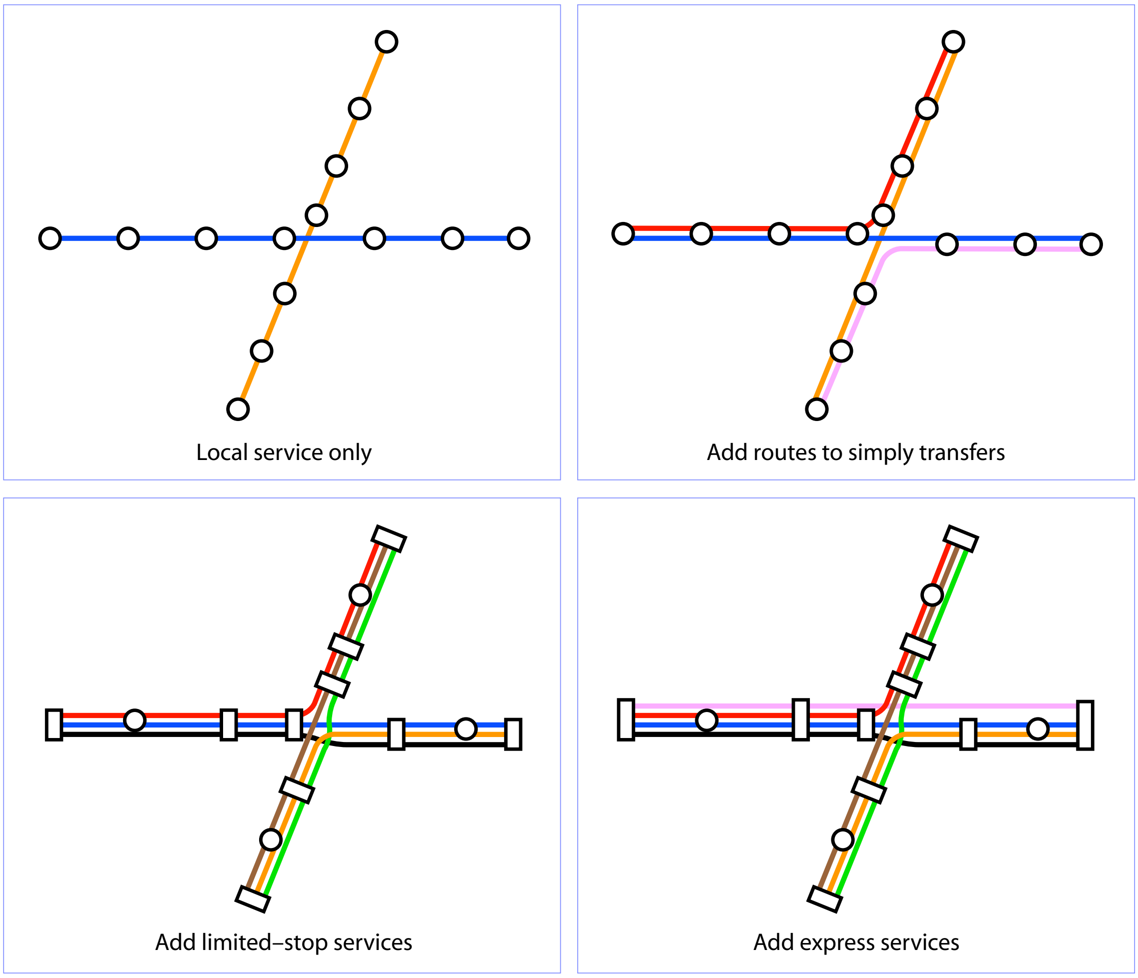


Fig. 7.38
Route-building process

The nature and organization of express and local services will depend on the nature of demand and where it is concentrated. Fully optimising public transport services makes it possible to find the right balance between local and express services which minimises the generalised trip cost for the most passengers. To do it properly requires a public transport system model, as described in Chapter 4 (*Demand analysis*).

Splitting services within a BRT corridor between local, limited stop, and express options, can dramatically increase the speed and capacity of a BRT system. This splitting of services is one of the key secrets to the high capacity and speed that was achieved with Bogotá's TransMilenio system. Getting the right mix of local and express services, however, is both difficult and critical in high demand systems.

7.3.6 Feeder routes

Connecting residential areas to the main BRT corridors is almost always essential to establishing a financially-sustainable public transport system. If a system only consists of major destinations with viable connections to trip origins, then customers will face difficulties in accessing the system. In high-quality BRT systems such as Bogotá and Curitiba, approximately one-half of system boardings originate from feeder services.

As this chapter has indicated, there are two service structures for linking main corridors to residential areas:

- Trunk-feeder services;
- Direct services.

This section provides an overview of choosing feeder routes within a trunk-feeder service. However, cities implementing systems with direct services will also need to give much consideration to how the route network extends into residential areas.

7.3.6.1 Selecting feeder routes

Normally, when a BRT system is built, many of the traditional bus and paratransit routes are removed from the corridor. The traditional routes generally operated both along the trunk corridor and off the corridor. The first step in identifying feeder routes is to look at those traditional bus and paratransit routes, and assign to feeder vehicles to those parts of the traditional routes that are not along the new BRT corridor. The traditional routes, however, are unlikely to be entirely optimal, and it is likely that new routes will need to be created using the data from the traffic model. Just as the demand analysis from Chapter 4 shaped the location of the trunk-line corridors, passenger demand profiles should also underpin feeder route selection. Both major residential areas and secondary commercial roadways are typically the focus of feeder services.

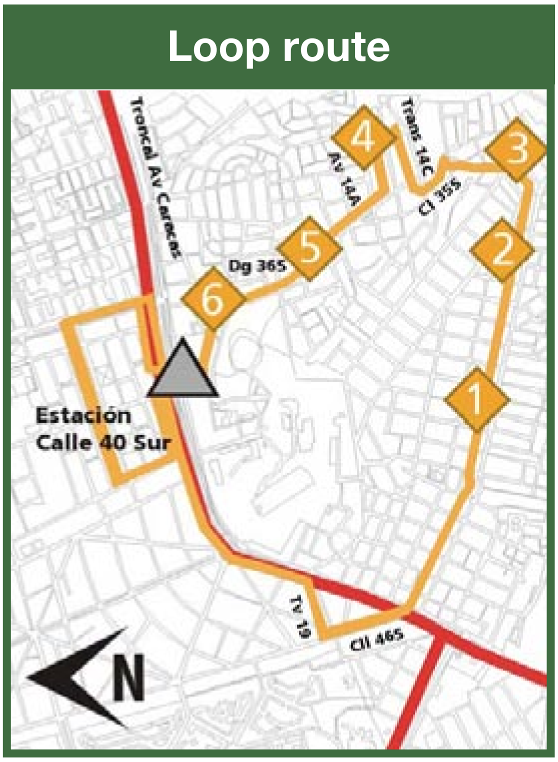
For distances beyond 500 metres from a trunk-line station, many customers will likely prefer a feeder service. Although some developing-nation cities report considerably longer walking distances for citizens to access public transport, these persons are often captive customers with few other options. Moreover, the footpath conditions in such cities are generally not of a high quality. Thus, the 500-metre rule should be one of the guiding principles in selecting feeder routes.

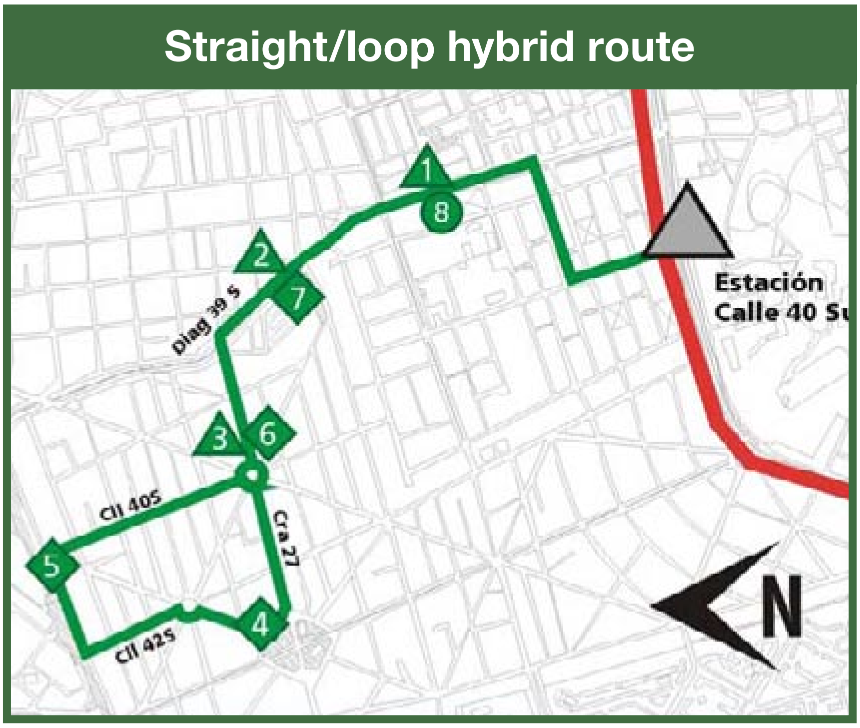
In most cases, the areas around the system's trunk terminals are a priority for feeder services. The terminal location will likely be chosen in part due to the nearby passenger capture area. Terminals are also the easiest place to facilitate transfers from feeder vehicles to trunk-line vehicles.

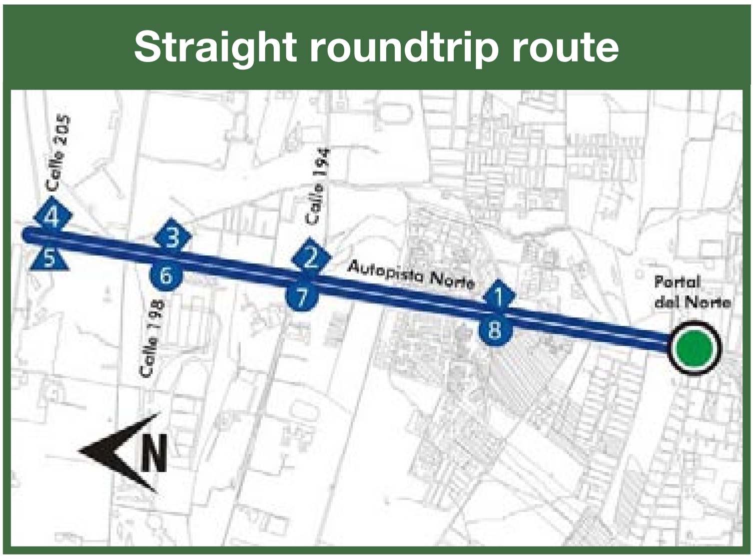
However, intermediate feeder opportunities should not be ignored. Very often secondary corridors that run perpendicular to the trunk corridor are fertile areas for customer demand. In such cases, some form of an intermediate transfer station must be provided to facilitate the feeder to trunk transfer.

The location of feeder services may also be influenced by social considerations. Low-income communities may be located in peripheral areas with poor road infrastructure. Smaller feeder vehicles are likely the only option for a system to access such areas effectively (Figure 7.39). Cities may elect to particularly emphasise feeder

Fig. 7.39
Smaller feeder vehicles are likely to be required in order to penetrate many low-income residential areas that may have a limited road network.
Photo by Shreya Gadepalli







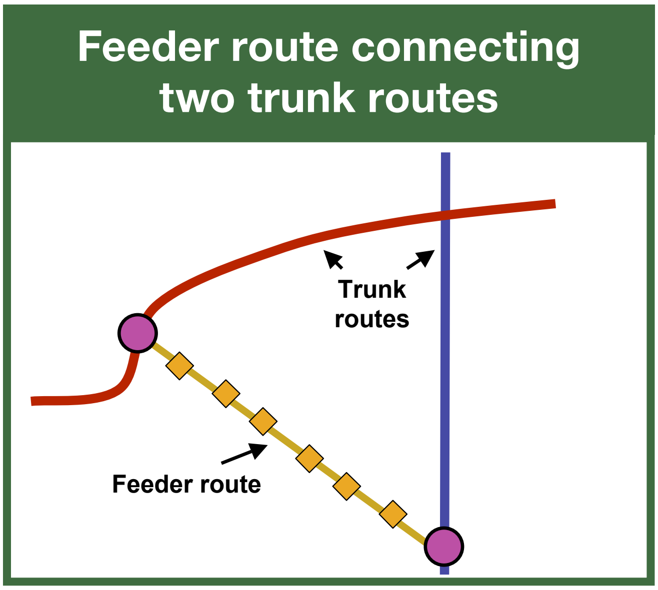


Fig. 7.40, 7.41, 7.42, and 7.43

Examples of different feeder route configurations in Bogotá.

Images courtesy of TransMilenio SA

connections for the poorest areas in order to better link such citizens to services and employment opportunities.

The overall length of feeder services will depend upon demand patterns and the relative population density of residential areas. The population density of a feeder area may be two to four times lower than the population density along a trunk corridor. Since feeder services are generally expected to deliver at least half of a system's ridership, the length of the total feeder routes may actually need to be two to four times greater than the length of the total trunk corridors.

The physical shape of a feeder route will depend upon local street configurations and demand profiles. However, in general, feeder routes tend to take upon one of these type of forms:

- Loop route (Figure 7.40);
- Straight roundtrip corridor (Figure 7.41);
- Combination of single corridor and loop route (Figure 7.42);
- Single corridor connecting two trunk corridors (Figure 7.43).

The loop route can be efficient from the standpoint of minimising duplication of services. The loop route maximises the area being covered by the feeder service (Figure 7.40). Rather than travelling "out and back" on the same corridor, the loop route allows the feeder vehicle to serve a new customer base along the entire length of the route. Thus, in some cases, operators earning revenues based on the number of passenger boardings may prefer a loop route.

However, a loop route has many disadvantages from a customer standpoint. Passengers boarding at the earliest portion of the loop route will have the longest travel time to arrive at the transfer terminal. Ironically, many of these passengers will actually reside closer to the terminal than passengers with a much shorter travel time. The reverse is also true for passengers returning to their residence. Passengers at the end of the loop line will have the longest travel time in order to travel from the terminal to their home. However, again, these passengers will likely reside much closer to the terminal than passengers with much shorter journeys. Thus, loop routes can create long and frustrating detour factors for many customers.

Loop routes can also create inefficiencies for operators. Along a loop route, passengers will be both boarding and alighting at each station. Thus, in terms of payment control and passenger counts, the task is more complex.

By contrast, a single corridor operating on an "out and back" routing avoids most of these difficulties (Figure 7.41). On the trip away from the terminal, most customers will be alighting. On the return leg, most customers will be boarding. Further, the length of time to the transfer terminal is directly proportional to a person's proximity to the terminal. However, a single roundtrip corridor will cover an area in a more limited fashion than a loop route. Thus, the out and back routing is not as cost effective in terms of covering a given area.

A reasonable compromise is to combine both the out and back routing with a loop routing (Figure 7.42). The loop route configuration would be attached to the end of straight roundtrip portion of the route. Thus, passengers living along the loop portion of the route are not heavily penalised with a large detour factor relative to the overall length of the route. At the same time, the addition of the loop improves the area coverage of the route and thus improves overall cost-effectiveness.

Perhaps the most effective feeder route structure, though, is a route directly connecting two different trunk corridors (Figure 7.43). In this case, the service retains the straight-line time efficiency of a single roundtrip corridor, but the cost-efficiency is improved with relatively uniform demand across the entire corridor length. In this configuration, customers will board and alight all along the corridor since there is a key destination (*i.e.,* a trunk-corridor station) at both ends of the corridor.

Of course, the actual optimum feeder service for any given situation will depend on many local factors, including the demand profile and the structure of the road network.

7.3.6.2 The dangers of ignoring feeder services

Can a BRT system operate only on major corridors without any supporting feeder services? Some cities have attempted to implement a busway system without providing either feeder services or direct services into residential areas. Typically, this arrangement occurs when a city wishes to implement a limited experiment on a major corridor during a BRT project's first phase. By doing so, the municipality can avoid addressing many of the complicated issues related to existing informal operators who service residential areas. The municipality can also avoid the complications related to the integration of services. However, the results to date on such an approach have not been entirely positive.

Jakarta (Indonesia) inaugurated its TransJakarta BRT system in January 2004 with an initial Phase I corridor of 12.9 kilometres. The system in this corridor consists of a single-lane median busway (Figure 7.44). The corridor is largely composed of business and shopping oriented destinations with few residential origins. The municipality tried to designate some pre-existing privately operated perpendicular routes as official feeder buses, and to give these bus passengers a discount on the BRT system, but the discount tickets were not honoured by the private bus operators, leading in effect to a 'trunk' system without a 'feeder' system.

The city also elected to allow the existing bus operators to continue operating in the mixed traffic lanes. While the system enjoys popular support and significantly reduces the travel time for trips along the corridor, it poorly serves many other transit passengers using the corridor. The limited BRT system carries 65,000 passengers per day and about 3,000 passengers per hour per direction at peak times. The continued operation of the existing operators in the reduced confines of the mixed traffic lanes has also exacerbated overall traffic congestion levels (Figure 7.45). As the system expands, these problems will be reduced, but a system of feeder buses would certainly have significantly increased demand and reduced mixed traffic congestion.

Jakarta's experience with the first phase of the TransJakarta system provides several lessons regarding the importance of feeder services and coordination with existing services. The lack of feeder services has created three troubling outcomes in Jakarta:

- Mixed first impression of BRT;
- Insufficient demand for a financially-viable BRT system;
- Increase in overall congestion levels.

While initial reaction to Jakarta's Phase I was mixed, many negative articles in the press and much consternation from private vehicles users could have been avoided.

Fig. 7.44
Phase I of the TransJakarta system provided a reasonable quality trunk service.
Photo courtesy of ITDP

Fig. 7.45
The lack of feeder services and the continued operation of existing services in the mixed traffic lanes exacerbated traffic congestion.
Photo courtesy of ITDP

8. System capacity and speed

"Speed provides the one genuinely modern pleasure."

—Aldous Huxley, writer, 1894–1963

"There is more to life than increasing its speed."

—Mahatma Gandhi, political leader, 1869–1948

Designing a BRT system to comfortably handle high passenger demand in a rapid manner is one of the pillars to delivering a car-competitive service. Since customers do not like to wait at stations and terminals, providing highly frequent services with a minimum of transfers must also be a principal design objective.

The capacity, speed, and service frequency of BRT systems are defining features that set it apart from conventional bus services. This chapter on operational planning thus addresses decisions affecting these basic parameters:

1. Sufficient system ***capacity*** to handle expected passenger demand;
2. Service ***speeds*** that minimise travel times;
3. ***Frequency*** of service to minimise waiting times.

However, high-capacity and high travel speed can be conflicting concepts. As the number of vehicles and passengers increase, the opportunity for bottlenecks and operational problems multiply. Identifying all the critical elements that may inhibit high-capacity and high-speed service is an important step towards effective design. This chapter outlines the design features that can enable a system to achieve both high capacity and high speed.

The topics discussed in this chapter are:

8.1 Calculating capacity requirements

"An optimist will tell you the glass is half-full; the pessimist, half-empty; and the engineer will tell you the glass is twice the size it needs to be."

—Anonymous

8.1.1 Design objectives

Once the BRT corridors and routes have been determined and once the basic service options have been selected, optimising conditions to handle the expected passenger demand in the most rapid manner possible becomes a design priority. System designers should aim to satisfy three general objectives:

1. Meet current and projected passenger demand;
2. Achieve average vehicle speeds of 25 kph or higher;
3. Minimise door-to-door travel times for customers.

8.1.1.1 High-capacity operations

In many cities, the provision of high-capacity capabilities is the principal design consideration. Recent experiences have firmly demonstrated that high-capacity operations can be achieved with BRT at a considerably lower cost than rail options.

However, in many cities with lower levels of demand on their main corridors, high capacity is not needed, and designing a high-capacity system may impose needless operating and capital costs on the city. Large vehicles, for example, are not always needed, and can even be detrimental to system performance. Inappropriately large vehicles will either operate with few passengers or result in infrequent service. In such instances, smaller vehicles will both improve profitability as well as better meet customer preferences, such as high-frequency services.

Fig. 8.1 and 8.2
Designing a system along corridors with demands exceeding 30,000 passenger per hour per direction (left photo, Bogotá) is quite different from designing for systems with less than 3,000 pphpd (right photo, Orlando).
Left photo by Carlos F. Pardo
Right photo by Lloyd Wright

The demand analysis and modelling process will help quantify existing public transport demand as well as provide projections of expected system growth. A system should be designed for expected capacities at least one to two decades into the future. The size of the growth cushion will depend upon how fast a city's population and mobility needs are increasing. For example, in some rapidly urbanising Chinese cities, growth rates of up to 25 percent are being realised over relatively short periods. In such instances, a growth cushion of 50 percent or higher may be appropriate for sizing the system's capacity requirements. In other regions that are already highly urbanised, such as Latin America, growth rates are much less. In cities of Latin America, a growth cushion of 25 percent would likely be adequate. A detailed modelling exercise will produce more precise growth estimates, and thus can be particularly useful in situations with high growth rates.

The specific design solutions to achieve high capacity will vary widely for different levels of demand. For example, a theoretical BRT system that only needs to handle a demand of 5,000 passengers per peak hour per direction (pphpd) will be significantly different than a system requiring over 30,000 pphpd (Figures 8.1 and 8.2). For example, a lower-demand system, where most of the demand is concentrated at two nodes at the beginning and the end, and faces bottlenecks only at one bridge and one intersection, and operates the rest of its route down an uncongested interstate highway, may only require an exclusive bus lane across the bottleneck and signal priority at the intersection. With these simple measures the capacity, speed, and total travel time targets can be achieved. Of course, providing an exclusive busway along the entire corridor creates the appearance of a more metro-like system that will likely be better perceived and understood by the greater population.

A high-demand corridor in a mega-city will require a different set of planning tools than those required for low-demand areas. In high-demand areas, full busway corridors are likely to be essential to removing the congestion delays that inhibit system capacity and speed.

8.1.1.2 High-speed operations

Busway systems can be designed to operate at high capacities, but in some cases, high demand designs have also produced relatively slow commercial speeds. Prior to the Bogotá TransMilenio system, the simple busway on the Avenida Caracas corridor was able to move over 30,000 passengers per hour per direction (pphpd), only marginally less than the current BRT system in the same corridor. However, due to significant congestion, the vehicles only averaged 10 kph. By comparison, the TransMilenio BRT system operates at an average commercial speed of approximately 27 kph.

8.1.1.3 Rapid travel times

In general, customers are not particularly aware of capacities or average speeds. These issues are of importance to operators and the administrative agency, but to customers the only number of importance will be the length of time to go from their trip origin to their trip destination.

Designing a high-capacity and high-speed BRT system does not guarantee that door-to-door travel times for customers are minimised. High-capacity and high-speed services can be achieved simply by eliminating all the stops along a BRT corridor, and having service run only between the two terminals. Metro systems are often designed with very long distances between station stops in order to increase average speeds and capacity. However, this decision has an adverse impact on door-to-door travel times, as customers will now have much further to walk to reach the nearest public transport station.

The system's design therefore has to be optimised not only in terms of speed and capacity but also in terms of minimising door-to-door travel times for the majority of passengers.

8.1.2 Defining terms

Achieving rapid, high-capacity operations is built upon many inter-dependent design components. This section defines terms that represent the building blocks for these components. The elements that support efficient customer and vehicle movements ultimately determine the speed and capacity performance of the system.

8.1.2.1 Station saturation

Understanding the ***saturation level*** of a station is a basic starting point in achieving high capacities and high speeds. The saturation level of a station refers to the percentage of time that a vehicle stopping bay is occupied. The term saturation is also used to characterise a roadway, and in particular, the degree to which traffic has reached the design capacity of the road.

When engineers talk about the capacity of a road or a BRT system, they will give a capacity for an acceptable ***level of service***, rather than for the maximum number of vehicles or passengers that could pass through a road or a system. After a certain point, the lane or BRT system

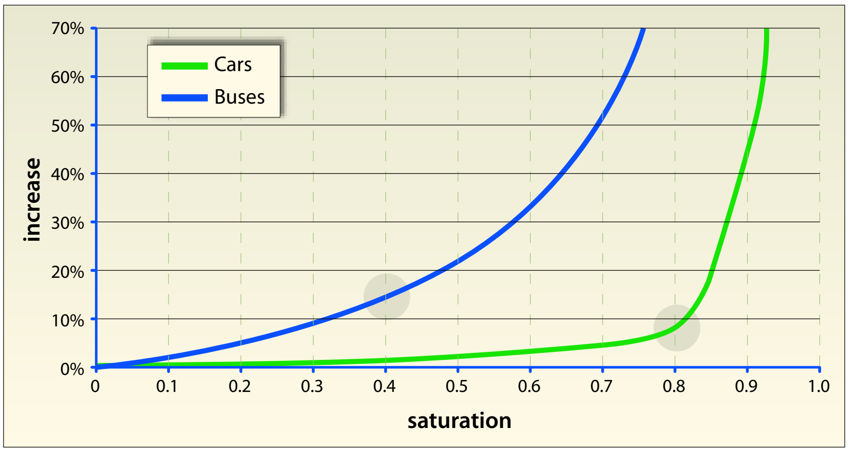


Fig. 8.3
Relationship between travel time and saturation levels

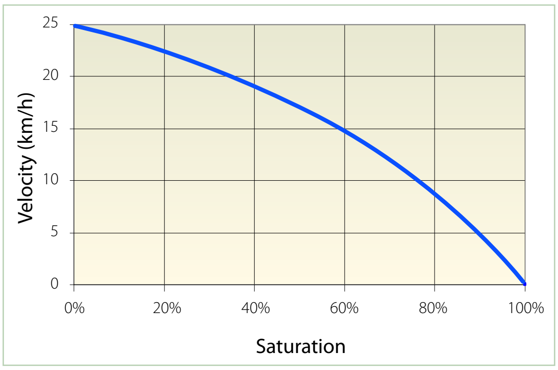


Fig. 8.4
Impact of saturation on vehicle velocity.

becomes congested. With congestion, the total flow of vehicles is still increasing, but the vehicles are going slower and slower, so that the level of service declines.

Commonly, for mixed traffic, a level of saturation of (x=) 0.85 is considered acceptable. Below a saturation level of 0.85, increases in traffic will have only a minimal impact on average speeds, and the level of service is acceptable. Once saturation levels exceed 0.85, there is a dramatic drop in speeds.

However, with BRT stations, there is no clear break point. Because bus activity is complex and irregular, stations can sometimes become congested even at low saturation levels of 0.1 to 0.3.

In general, stations should be at less than 40 percent saturation or else the risk of congestion increases significantly. The impact of stopping bay saturation on speed is shown in Figure 8.4.

Rather than a clear point at which the system collapses, station saturation tends to lead to a gradual deterioration of service quality. For this reason, the optimum level of station saturation is not clear. Some studies argue that the optimum should be around 0.30, but saturation levels as high as 0.60 can be tolerated in specific locations if this condition is not general throughout a BRT corridor. However, for saturation levels above 0.60, the risk of severe congestion and system breakdown is considerable.

A low saturation level or a high level of service means that there are no vehicles waiting in queue at a stopping bay. A high saturation level means that there will be long queues at stopping bays. For saturation levels over one (x > 1), the system is unstable with queues increasing until the system does not move.

Fig. 8.5
The use of multiple stopping bays and passing lanes in Bogotá helps minimise bus congestion.
Photo courtesy of Oscar Diaz and Por el País que Queremos (PPQ)

8.1.2.2 Stopping bay

A ***stopping bay*** is the designated area in a BRT station where a bus will stop and align itself to the boarding platform. In the first BRT systems, each station had only one stopping bay. A key innovation of Bogotá's TransMilenio system was that more capacity and speed could be obtained if at each station, instead of having just one stopping bay, there were multiple stopping bays (Figure 8.5).

By adding more stopping bays, the saturation level of each stopping bay could be kept to a maximum value of 0.40. TransMilenio strives to keep the maximum variation in the saturation value at no more than 0.10 between stations, so the values should not vary from a range of 0.35 to 0.45.

The "Calle 76" station of the TransMilenio system illustrates the importance of accurately projecting passenger movements and station saturation levels. Originally, this critical station was planned for a saturation level of 0.40. However, many more people chose to transfer at this station than was anticipated. While the planners predicted 32 passengers would be boarding and alighting during the peak hour, in fact, 75 are currently boarding and alighting. The present saturation level on that station is approximately 0.65. There are some queues and delays of up to 1.5 minutes, but just at this station. If the saturation level continues to rise further, this problem could lead to system gridlock.

8.1.2.3 Service frequency and headways

The ***service frequency*** refers to the number of buses per hour. The waiting time between

Fig. 8.6
Service frequency and the potential impact on vehicle velocity.
Source: Steer Davies Gleave

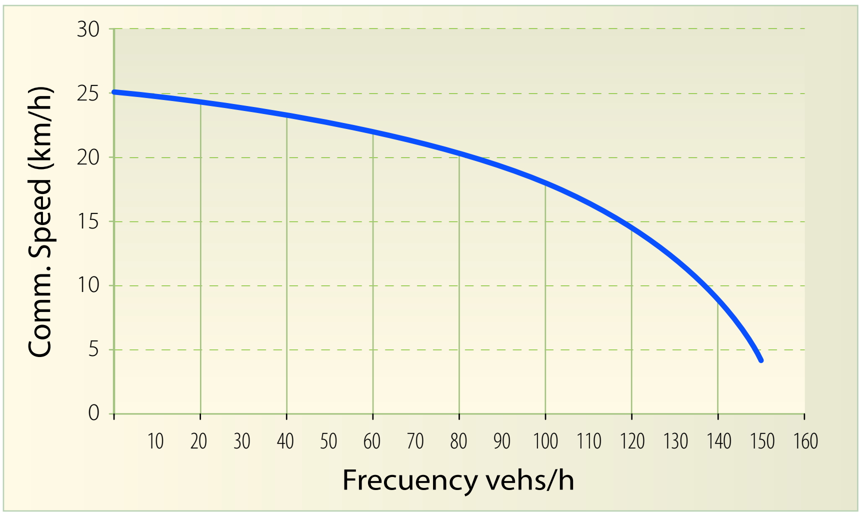


Fig. 8.7 and 8.8
The perception of a relatively empty busway next to heavily-congested mixed traffic lanes, as seen in these images of Quito (left photo) and Hangzhou (right photo), can create political pressures.
Left photo by Lloyd Wright
Right photo by Kangming Xu

vehicles, which is roughly the same idea, is known as the ***headway***. In general, it is desirable to provide frequent services in order to reduce customer waiting times. Customers often perceive waiting times to be much longer than the actual duration.

On the other hand, if headways are very low, and frequency is high, the danger of stopping bay congestion and slower speeds increases. Figure 8.6 illustrates the relationship between service frequency and congestion. Thus, a key objective is to minimise customer waiting by balancing the impact of headways on stopping bay saturation.

Service frequency varies between different cities with BRT based on demand, but in general, one of the key innovations of TransMilenio was dramatically increasing service frequency by reducing delays at the stations. A vehicle will pass any given point on TransMilenio's corridors every 20 seconds. Peak frequencies of 60 seconds to 90 seconds are now quite common on BRT systems. However, frequency per stopping bay tends to be around one minute.

When services become infrequent, the impact is not only on waiting passengers. Car drivers in traffic congestion will become frustrated from seeing an empty busway beside them. In turn, motorists will complain that the road is being under-utilised. Such complaints ultimately undermine political support for future busways (Figures 8.7 and 8.8). While a headway of a few minutes may not seem like a lot of time, the sight of a busway with a vehicle only passing every few minutes can appear to be empty most of the time. In Quito, pressure from motorist organisations led the national police to open-up exclusive busway corridors to mixed traffic for a period of time in 2006. This conversion occurred despite the fact that each busway lane was moving 3 to 4 times the volume of passengers as a mixed traffic lane. Nevertheless, the perception of an empty busway next to heavily congested mixed traffic lanes can create political difficulties.

Non-peak frequencies are likely to be longer due lower passenger demands. However, if non-peak headways are excessively long, the system's viability will be undermined. To a waiting passenger, five minutes can seem like a long time, especially if one is in a hurry to arrive at the destination. At headways of ten minutes or longer, passengers will no longer regard the system as a metro-like service. Instead, at this point, passengers will tend to view the system as a timetable service.

On the other hand, if frequencies are too high relative to demand, the profitability of the system will suffer. Service during weekends may also tend to follow non-peak frequencies. However, weekend services may also require peak and non-peak schedules, depending upon local circumstances. For example, weekend markets and sporting events may necessitate higher frequency services.

8.1.2.4 Load factor

The ***load factor*** is the percentage of a vehicle's total capacity that is actually occupied. For

Fig. 8.9
Due to unexpectedly high demand, the Avenida Caracas corridor in Bogotá sometimes suffers from overcrowding at peak periods.
Photo by Carlos F. Pardo

Fig. 8.10
The Manila LRT1 and MRT3 systems are managed to operate almost constantly at crush capacity, making usage somewhat unpleasant.
Photo by Lloyd Wright

example, if a vehicle has a maximum capacity of 160 passengers and an average use of 128 passengers, then the load factor is 80 percent (128 divided by 160). The actual load factor of any BRT system is determined by the frequency of the vehicles and the demand. The load factor can be changed by changing the frequency of the services or changing the routes of competing services.

While systems with high load factors tend to be more profitable, generally, it is not advisable to plan to operate at a load factor of 100 percent. At a 100 percent load factor the vehicle is filled to its recommended maximum capacity. Such conditions are not only uncomfortable to passengers, but also create negative consequences for operations. At 100 percent capacity, small system delays or inefficiencies can lead to severe over-crowding conditions.

The desired load factor may vary between peak and non-peak periods. In the Bogotá TransMilenio system, typical load factors are 80 percent for peak periods and 70 percent for non-peak periods. However, as ridership levels are increasing in Bogotá, over-crowding is an increasing concern (Figure 8.9).

Systems can also sometimes operate at a load factor exceeding 100 percent. Such a level implies that passengers are more closely packed than the maximum recommended levels. This situation is sometimes known as the "crush capacity" of a system. While such extreme capacities can be expected in some unusual circumstances (*e.g.,* immediately after special events such as sporting events or concerts), it is not desirable to regularly overcrowd vehicles.

Due to operational cost reasons, some rail systems are forced to operate at an almost continuous state of crush capacity. The frequencies of the LRT1 and MRT3 systems in Manila are timed to maximise the load factor at all times of the day (Figure 8.10). Due to the subsidies required for operation, the Manila system operators are forced to minimise costs through high load factors. However, in the long term, such conditions simply encourage public transport users to switch to private vehicles.

8.1.2.5 Dwell time

The amount of ***total stop time per vehicle*** will affect the system's overall efficiency. The amount of time that any given vehicle is occupying a given stopping bay is known as the ***dwell time***. Total stop time per vehicle is the contribution to stopping bay saturation that each vehicle adds. The dwell time consists of three separate delays: ***boarding time***, ***alighting time***, and the ***dead time***. Some of the factors affecting dwell time include:

- Passenger flow volumes;
- Number of vehicle doorways;
- Width of vehicle doorways;
- Entry characteristics (stepped or at-level entry);
- Open space near doorways (on both vehicle and station sides);
- Doorway control system.

BRT systems are able to operate metro-like service in large part due to the ability to reduce total stop time to 20 seconds or less. A conventional bus service often requires over 60 seconds for stop time, though the specific time will be a function of the number of passengers and other factors. In general, dwell times may be somewhat higher during peak periods than non-peak periods. The increase during peak periods is due to the additional time needed to board and alight the higher customer volumes.

The dwell time is one major element affecting average commercial speed. Every second of delay at the stopping bay leads to a deterioration of average speed. However, there are also two other elements of vehicle stopping that affects speed and travel time. The rate of vehicle deceleration, when approaching a stopping bay, and the rate of acceleration, when departing a stopping bay, are also key factors. The deceleration and acceleration rates often involve a trade-off between speed and customer comfort, as well as the ability to properly align the vehicle to the stopping-bay interface.

An abrupt deceleration will cause passengers to lunge forward, making reading or other travel-time activities quite difficult. The impact on standing passengers can be particularly jarring. Likewise, a rapid deceleration can cause the driver to misalign the vehicle with the platform, making boarding and alighting difficult. While BRT operations are not likely to ever be as smooth as a well-operated rail systems, improvements in vehicle technology and operational practices can minimise the discomfort of slowing and stopping.

8.1.2.6 Renovation factor

The ***renovation factor*** is defined as the average number of passengers that are on a vehicle divided by the total boardings along a given route. For example, if 50 is the average number of people on a vehicle at any given time going from point A to point B, but 200 people are boarding the bus between these points, then the renovation factor is 25 percent. The lower the renovation factor, the higher the usage rate of the vehicle, regardless of the vehicle's physical attributes. In this respect, a high number of boardings and alightings increases the effective capacity of the vehicle.

Corridors with very low renovation factors are extremely profitable because the same number of total paying passengers can be handled with many fewer buses. For example, the new Insurgentes corridor in Mexico City has recorded renovation factors of 20 percent, which means that five times more people getting on and off the vehicle as there are people on the vehicle at any given time (Figure 8.11).

Fig. 8.11
The Insurgentes corridor in Mexico City.
Photo by Bill Vincent, Breakthrough Technologies

8.1.3 Calculating corridor capacity

8.1.3.1 Basic calculation

Equation 8.1 shows the basic relationships between the main factors that affect the capacity of a BRT system: vehicle capacity, load factor, service frequency, and the number of stopping bays. The renovation factor will not be affected by the system design, but it is important to keep in mind when calculating capacity.

Equation 8.1 Basic formula for corridor capacity

$$\text{Corridor capacity (pphpd)} = \text{Vehicle capacity (passengers/vehicle)} \times \text{Load factor} \times \text{Service frequency (vehicles/hr)} \times \text{Number of stopping bays}$$

Table 8.1 below shows sample corridor capacities for a range of common scenarios. By varying only the vehicle capacity and the number of stopping bays per station, it shows just how powerful these two factors are in determining system capacity. The values in this table are merely examples; the actual potential capacities for a given city will vary depending on a variety of local circumstances.

The values presented in table 8.1 above are possible values, but Equation I tells little about how these values were achieved, or how they might be achieved in another city. These values assume that the vehicles operate on a segregated, median-aligned busway with at-level boarding. Values will be lower for curbside busways where there are significantly more turning conflicts with other vehicles. Further, if the vehicles have stepped passenger entry instead of at-level entry, longer headways will be necessary to handle the additional dwell times.

Table 8.1: BRT corridor capacity scenarios

Vehicle capacity[1] (passengers)	Load factor	Vehicle frequency per hour per stopping bay	Number of stopping bays per station	Capacity flow (passengers per hour per direction)
70	0.85	60	1	3,570
160	0.85	60	1	8,160
270	0.85	60	1	13,770
70	0.85	60	2	7,140
160	0.85	60	2	16,320
270	0.85	60	2	27,540
70	0.85	60	4	28,560
160	0.85	60	4	32,640
270	0.85	60	4	55,080
160	0.85	60	5	40,800
270	0.85	60	5	68,850

The number of stopping bays also affects the type of busway infrastructure. Unless operating in a controlled convoy, stations with two or more stopping bays will require passing lanes or double sets of busway lanes. As the number of stopping bays increase to four or more, then it is likely that double sets of lanes will be required along the entire length of the busway. Otherwise, congestion will likely occur.

Below are some sample values for a variety of factors affecting BRT passenger capacity. Table 8.2 summarises these values.

The sample values represent the findings from a survey of existing BRT systems. However, they are presented for purely demonstrational purposes. The actual figures for a given set or circumstances are highly dependent upon local factors. To

Table 8.2: Sample values from existing BRT systems

Factor	Typical range
Vehicle capacity, standard-sized bus	60 – 75 passengers
Vehicle capacity, articulated bus	140 – 170 passengers
Vehicle capacity, bi-articulated bus	240 – 270 passengers
Load factor, peak period	0.80 – 0.90
Load factor, non-peak period	0.65 – 0.80
Headways per stopping bay, peak period	1 – 3 minutes
Headways per stopping bay, non-peak period	4 – 8 minutes
Dwell time, peak period	20 – 40 seconds
Dwell time, non-peak period	17 – 30 seconds
Number of stopping bays	1 – 5 stopping bays

[1] Standard-sized bus (12 metres): 70 maximum passengers. Articulated bus (18.5 metres): 160 maximum passengers. Bi-articulated bus (24 metres): 270 maximum passengers.

calculate the actual capacity of a specific system being designed in a different city, the following far more complex formula is generally used. To understand the entirety of this formula will require considerable explanation.

8.1.3.2 Detailed capacity calculation

The capacity calculation given above (equation 8.1) above does not detail the precise interrelationships between different design factors, such as vehicle size, dwell times, and renovation factors. Determining the actual capacity of a proposed system requires understanding these relationships. For example, as the number of boardings and alightings increase, dwell times will tend to increase and capacity will be repressed. Further, the equation does not account for the additional capacity benefits gained from limited-stop and express services.

A more detailed capacity formula is thus given as follows:

Equation 8.2 Capacity formula

$$Co = \frac{Nsp * X * 3{,}600}{\left[\frac{Td * (1 - Dir)}{Cb} + (Ren * T1)\right]}$$

Where:

Co = Corridor capacity (in terms of passengers per peak hour per direction or pphpd)
Nsp = Number of stopping bays
X = Saturation level
3,600 = Number of seconds in an hour
Td = Dwell time
Dir = Percentage of vehicles that are limited-stop or express vehicles
Cb = Capacity of the vehicle
Ren = Renovation rate
T1 = Average boarding and alighting time per passenger

The saturation rate shows the amount of time that a stopping bay is occupied by vehicles. In order to ensure an acceptable level of service, the saturation rate must be carefully selected. An acceptable level of service is typically defined as the ability to achieve an average commercial speed of 25 kph. The general assumption for achieving this level of service is a saturation of approximately 40 percent (X = 0.4) or less. Thus, for the purposes of the examples presented in this chapter, the saturation level will be set at 0.4. The corridor capacity equation thus becomes:

Equation 8.3 Calculating corridor capacity

$$Co = \frac{Nsp * 1{,}440}{\left[\frac{Td * (1 - Dir)}{Cb} + (Ren * T1)\right]}$$

where, from the previous equation:

X = 0.4

0.4 * 3,600 seconds = 1,440 seconds

This formula is the calculator that will be used throughout the rest of the chapter to calculate the impacts of different design changes on corridor capacity. Each part of this equation will be broken down into its various sub-parts in order to develop a better understanding on how each component affects corridor capacity.

8.1.4 Designing for rapid, high-capacity services

A system will only move as quickly as its slowest point. Identifying this weak link in the system is the foundation for improving capacity and travel times. In general, one of three critical factors will represent the bottleneck point on a public transport system:

- Passenger delays in boarding and alighting;
- Vehicle congestion at stations;
- Vehicle congestion at intersections.

In most cases, the critical factor in developing a rapid, high-capacity system will be de-congesting the station areas. The fact that BRT systems are now able to reach speeds and capacities comparable to all but the highest capacity metro systems is principally due to dramatic improvements in vehicle capacity at stations. Other factors are also important to reaching these speed and capacity goals, but none are as important as stopping bay congestion. Designing an effective BRT system requires a thorough understanding of the causes of stopping bay delay and how to solve them. Many existing BRT systems are burdened with slow operating speeds due to incorrect demand projections at particular stations. Poorly designed stations can lead to peak-hour vehicle queues that stretch for several hundred metres. For optimum performance, each stopping bay should be designed and dimensioned to the specific demand at that bay.

The specific factors that will most likely affect customer and vehicle flows are:

- Size of the vehicle;
- Vehicle-stopping bay interface;
- Number of stopping bays at each station;
- Number of express and local bus services;
- Frequency of stations;
- Load factor per vehicle;
- Intersection design;
- Station design (station size, characteristics of pedestrian access, number of turnstiles, etc.).

The remaining sections of this chapter will review the various techniques that can be utilised to overcome these potential bottleneck points.

8.2 Vehicle size

"Size matters not. Look at me. Judge me by my size, do you? Hmm? Hmm. And well you should not."

—Yoda (Star Wars)

Most decision makers unfamiliar with BRT systems assume that the secret to a high-capacity and high-speed system lies in the procurement of larger vehicles. While larger vehicles are one contributing factor, they are rarely the principal component in realising rapid, high-capacity services. Station efficiency is more likely to be the critical factor in optimising system operations. However, the size and design of the vehicle will be an important decision factor, especially in terms of ensuring customer convenience and comfort.

8.2.1 Vehicle size options

As has been noted, system designers have many vehicle size options. The right vehicle size is not always the largest vehicle. The main advantage of larger vehicles stems from reductions in operating costs, especially driver labour costs per passenger carried. However, in lower-demand corridors, these large vehicles also tend to mean lower frequency, and hence longer waiting times for passengers. Table 8.3 summarises the standard vehicle sizes available to system developers.

Table 8.3: Trunk corridor vehicle options

Vehicle type	Vehicle length (metres)	Capacity (passengers per vehicle)
Bi-articulated	24	240 – 270
Articulated	18.5	120 – 170
Standard	12	60 – 80
Mini-bus	6	25 – 35

Increasingly, the 18.5-metre articulated vehicle is becoming the standard for BRT systems (Figure 8.12). To date, only the Curitiba system has utilised the larger bi-articulated vehicles. There are several reasons for the current dominance of the articulated vehicles (160 passenger capacity) over the bi-articulated vehicle (270 passenger vehicle):

- Large numbers of articulated vehicle orders have produced cost savings through economies-of-scale in manufacturing;
- Currently only a few manufacturers offer a bi-articulated vehicle, and thus limiting the power of competition during the bid process;
- Heavier weight of bi-articulated vehicles reduces fuel efficiency and ability to accelerate rapidly;
- Length of bi-articulated vehicles (24 metres) can create difficulties with regard to available length of right-of-way at stations.

Fig. 8.12
The 18.5-metre articulated vehicle has become standard in many BRT applications.
Photo by Kangming Xu (http://www.brtchina.org)

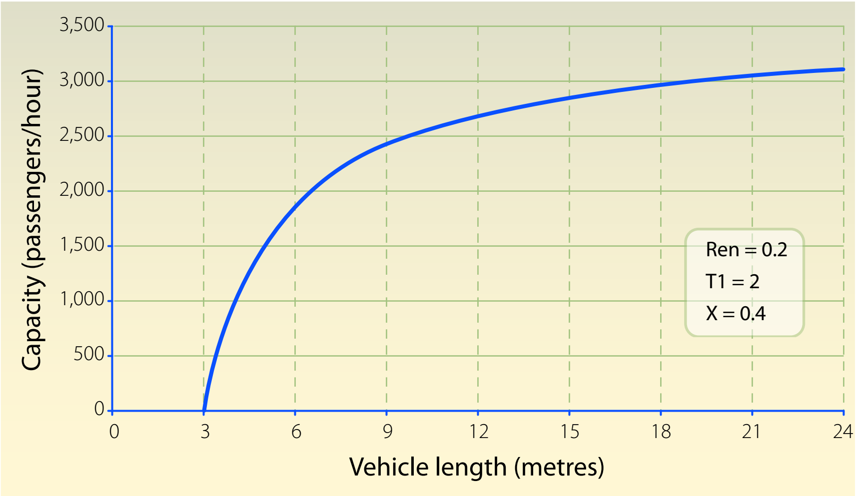


Fig. 8.13
Example curve for vehicle size versus capacity.

However, there may be instances, where the operational and physical characteristics of a corridor would make a bi-articulated vehicle an appropriate choice. Likewise, there are many lower-demand circumstances where a standard-sized vehicle (12 metres) would be the optimum choice. In general, mini-buses and van-sized vehicles would not be utilised in trunk corridor operations given their carrying-capacity limitations. Such vehicles, though, may be appropriate for feeder operations.

Chapter 12 (*Technology*) discusses most aspects of vehicle technology options.

As vehicle length increases, there can be a diminishing return in terms of delivered capacity. If stopping bay capacity and vehicle congestion occurs, then the additional capacity may not be fully realised. Figure 8.13 gives an example of this effect for a given set of parameters.

8.2.2 Vehicle size and corridor capacity

Higher vehicle capacity can in the right circumstances increase BRT system capacity. Normally, a vehicle can hold an additional 10 passengers for every additional metre of length, less the space for the driver and engine, which is usually estimated to be 3 metres. The actual number of passengers per metre of length is actually fairly culturally dependent. In some cultures, a fairly packed spatial arrangement is acceptable. In these instances, customers may not be offended by some contact between persons. In other cultures, there may be a greater need for each person's own personal space. The value of 10 passengers per metre of length is an average value across existing systems. System planners will need to make some assumptions about acceptable levels of crowdedness within the vehicle to accurately set this value.

For conventional vehicles, Equation 8.4 summarises the relationship between vehicle size and vehicle capacity.

Equation 8.4 Calculating vehicle capacity from vehicle length

$$\underset{\text{(Passengers/vehicle)}}{\text{Vehicle capacity (Cb)}} = \underset{\text{(Persons/metre)}}{10} \times \left[\underset{\text{(Metres)}}{\text{Length of vehicle (L)}} - \underset{\text{space for driver)}}{\text{3 (Metres of}} \right]$$

$$Cb = 10 \times (L - 3)$$

The calculation will be somewhat different for double-decker vehicles, which do not lose space to the driver and engine on the second deck, although such vehicles do lose space to the stairway.

Vehicle size also affects the dwell time. Most vehicles require about 10 seconds to open and close their doors and pull in and out of a station. However, if the vehicle is larger, an additional 1/6 of a second per metre of vehicle is generally required for pulling in and out of the station. Therefore, dwell time can be calculated as indicated in the following equation.

Equation 8.5 Impact of vehicle length on dwell time

$$\underset{\text{(Seconds)}}{\text{Dwell time (Td)}} = \text{10 (Average time for pulling in and out of bay) (Seconds)}$$

$$+ \text{1/6 additional second for each additional metre of vehicle lenght (L/6) (Seconds)}$$

$$Td = 10 + (L / 6)$$

If these calculations for vehicle capacity (Cb) and dwell time (Td) are inserted into the calculation for corridor capacity, then the result is equation 8.6.

Equation 8.6 Corridor capacity calculation

$$Co = \frac{Nsp * 1{,}440}{\left[\dfrac{(10 + L/6) * (1 - Dir)}{10 * (L - 3)} + (Ren * T1) \right]}$$

8.2.3 Optimising vehicle size

Determining the optimal vehicle size is usually one of the last decisions that should be made when designing a BRT system. It should be done only after the number of stopping bays and other considerations have already been decided. The relative costs of vehicle operations relative to waiting times must also be considered first.

Using the equation from before as a basis for vehicle sizing, the required vehicle size could be calculated as in Equation 8.7.

Equation 8.7 Determining required vehicle capacity

$$\text{Vehicle capacity (Cb) (passengers/vehicle)} = \text{Corridor capacity (Co) (pphpd)} \Big/ \left[\text{Load factor (Lf)} \times \text{Service frequency (F) (vehicles/hr)} \times \text{Number of stopping bays (Nsb)} \right]$$

$$Cb = \frac{Co}{[\,Lf \times F \times Nsb\,]}$$

This approximate calculation can be used when the saturation level of the stopping bay is not critical (*i.e.,* the bus stop is occupied less than 40 percent of the time). In such a case, the vehicle size decision should be based on the size of the maximum passenger load on the critical link that yields a reasonable frequency and a reasonable load factor. For example, a potential vehicle frequency could be one minute, and a reasonable load factor would be .85 or below. If the demand analysis indicates a corridor capacity of 15,000 pphpd and two stopping bays per station are assumed to be needed, then the optimal vehicle size would be calculated as:

$$Cb = \frac{15{,}000 \text{ pphpd}}{[\,0.85 \times 60 \text{ vehicles / hr} \times 2\,]}$$

$$= 147 \text{ passengers per vehicle}$$

Thus, in this example, 160-passenger articulated vehicles would be sufficient for this corridor.

8.2.4 Size of vehicle fleet

The chosen vehicle capacity will directly determine the number of vehicles required for a corridor. Procurement of larger vehicles will reduce the total number of vehicles required (Figure 8.14). Smaller vehicles will require more vehicles to be purchased, but as noted earlier, smaller vehicles will also contribute higher-frequency services and thus shorter customer waiting times. Also, the cost of a vehicle is fairly proportional to its size, so there is not necessarily a cost penalty for purchasing smaller vehicles. However, each additional vehicle does add to total operational costs due to the need for an additional driver.

The factors involved in determining the operational size of the vehicle fleet include:

- Peak passenger demand at the critical point along a corridor
- Total travel time to complete a full travel cycle along the corridor
- Capacity of vehicle.

Fig. 8.14
The size of the required vehicle fleet demands on corridor demand, travel time to complete a corridor cycle, and each vehicle's passenger capacity.
Photo by Lloyd Wright

A larger fleet size will be required as the length of the corridor and the total travel time increases. Equation 8.8 provides the calculation for determining the operational fleet size for a particular corridor.

Equation 8.8 Calculating operational fleet size for a corridor

$$\text{Operational fleet size for corridor (Fo)} = \text{Demand on critical link (D) (pphpd)} \times \text{Travel time for a complete cycle (Tc) (hours)} \;/\; \text{Vehicle capacity (Cb) (passengers/vehicle)}$$

$$Fo = \frac{D \times Tc}{Cb}$$

As an example, if the demand along a corridor is 10,000 pphpd using a vehicle with an operational capacity of 140 passengers and requiring one hour to traverse a complete cycle of the corridor, then the required operational fleet size will be:

$$Fo = \frac{10{,}000 \text{ pphpd} \times 1 \text{ hour}}{140 \text{ passengers / vehicle}} = 72 \text{ vehicles}$$

In this case, the corridor operations will require a fleet size of 72 vehicles.

In addition to the operational fleet, system planners will also have to factor in a contingency value. A certain percentage of vehicles should be withheld from service in case of problems with the operating fleet. Some vehicles may have mechanical problems while others may be undergoing routine inspection and maintenance procedures. These contingency vehicles will thus fill the operational void whenever some vehicles are out of service. A contingency factor of 10 percent is commonly utilised. Equation 8.9 gives the calculation for the total required fleet for a particular corridor, including both operational and contingency vehicles.

Fig. 8.15
Curitiba's innovations with station design and the station-to-vehicle interface did much to make BRT a high-capacity option.
Photo courtesy of Volvo

Equation 8.9 Calculating the total fleet size for a corridor

$$\text{Total fleet size (Ft)} = \text{Operational fleet size for corridor (Fo)} + \left[\text{Operational fleet size for corridor (Fo)} \times \text{Contingency value (Cv)} \right]$$

$$Ft = Fo + (Fo \times Cv)$$

Based on the previous example for calculating the operational fleet size and an assumed contingency value of 10 percent, the total fleet required for the corridor will be:

$$Ft = 72 + (72 \times 0.1) = 79 \text{ vehicles}$$

In reality, there should not be any dedicated contingency vehicles that are always withheld from service. Instead, all vehicles should be rotated between operational service, maintenance, and contingency status. This practice ensures a relatively equal number of kilometres for each vehicle in the fleet.

8.3 Vehicle-station interface

"Let every man praise the bridge that carries him over."

—English proverb

The innovations introduced by the Curitiba system, beginning in 1974, profoundly shaped the course of BRT (Figure 8.15). In particular, four of the most important innovations from Curitiba involved the vehicle-station interfacen:

1. Pre-board fare collection and fare verification;
2. At-level, platform boarding;
3. Efficient vehicle alignment to station;
4. Wide, multiple doorways;
5. Sufficient customer space on station platform.

Fig. 8.16
On-board fare collection and fare verification dramatically slows customer throughputs, as evidenced here in Goiânia (Brazil).
Photo by Lloyd Wright

These features heralded the advent of rubber-tyred based systems that could begin to emulate the performance of rail transit. Curitiba's innovations to the vehicle-station interface have enabled BRT systems to achieve quick boarding and alighting times (and therefore low dwell times). In turn, the low dwell times have been a cornerstone of alleviating vehicle congestion at stations and ultimately higher-capacity service.

From the main corridor capacity equation, measures improving the vehicle-station interface all help to reduce T1, which is the average boarding and alighting time per passenger.

$$Co = \frac{Nsp * 1{,}440}{\left[\frac{Td * (1 - Dir)}{Cb} + (Ren * T1)\right]}$$

This section discusses the particular techniques for improving boarding and alighting times.

8.3.1 Off-board fare collection and fare verification

Most BRT systems since Curitiba have instituted ***external*** or ***off-board fare collection*** and ***fare verification***. Passengers pay their fare prior to entering the station, and then have their fare verified as they pass the entry turnstile.

8.3.1.1 Time savings

With most conventional bus services, the driver is responsible for the collection of fares as well as driving the vehicle, and passengers are only allowed to enter through the front door. Thus, on-board fare collection means that boarding time is largely determined by the fare collection activity. If the fare collection process is slow, the whole public transport service is slow. Typically, passengers take from 2 to 4 seconds just to pay the driver. If drivers also have to give passengers change manually, even longer delays are seen. Once passenger flows reach a certain point, the delays and time loss associated with on-board fare collection become a significant system liability (Figure 8.16).

By contrast, in a BRT system with pre-board fare collection, boarding and alighting is conducted from all doors at once. When fares are collected off the vehicle, there is no delay in boarding and alighting related to the fare collection and fare verification processes. A pre-board fare collection and verification process will reduce boarding times from 3 seconds per passenger to 0.3 seconds per passenger. In turn, the reduction in station dwell time greatly reduces vehicle congestion at the stopping bay.

The introduction of contactless smart cards and other modern payment systems can reduce on-board payment to below 2 seconds per passenger. Systems such as the Seoul busway make use of on-board fare collection using smart card technology (Figure 8.17). However, any time the driver is responsible for verifying fares, the speed of the service will be highly compromised, particularly if there is a large volume of passengers.

Fig. 8.17 and 8.18
The Seoul busway system uses smart card technology for fare collection (left photo). However, the on-board nature of the fare verification means that dwell times are negatively affected. A single passenger searching through personal effects for their smart card can create a significant delay (right photo).
Photos by Lloyd Wright

In the case of the Seoul busway system, passengers must remember to swipe their smart card both upon entering the vehicle and when existing as well. Delays can occur simply if a person enters the vehicle and must search through their belongings to find the fare card (Figure 8.18). On-board payment and verification psychologically also creates a lower-market image for the service. Off-board payment and verification gives the sense of a more metro-like system.

With on-board fare collection and verification, alighting is usually faster than boarding. Typically, alighting times are approximately 70 percent of boarding times. In the case of off-board fare collection and verification, there usually is no significant difference between boarding and alighting times. Thus, an average time for both boarding and alighting can be used for the variable T1.

8.3.1.2 On-board and off-board options

Off-board payment collection is not necessarily the only way to reduce boarding and alighting times, but there are institutional reasons why this approach is generally more successful in the developing-country context. Passengers can also enter through all doors at once if there are sufficient conductors to check tickets once on board. Alternatively, many European light rail systems utilise and honour system, where it is the responsibility of passengers to punch their own tickets which they purchase at shops and kiosks. Enforcement is then the responsibility of the police or contracted security personnel. However, in developing countries such enforcement is usually ineffective.

Another reason for off-board fare collection and verification is that it enhances the transparency of the process of collecting the fare revenues. When passengers pay on board, and do not have to pass through a turnstile, there is no clear count of how many passengers boarded the vehicle. Off-board fare sales to a third party make it easier to separate the fare collection process from the bus operators. By having an open and transparent fare collection system, there is less opportunity for circumstances in which individuals withhold funds. This separation of responsibilities has regulatory and operational advantages that will be discussed later. Further, by removing the handling of cash by drivers, incidents of on-board robbery are reduced.

Off-board payment also facilitates free transfers within the system. The enclosed, controlled stations also give the system another level of security, as the stations can be better protected by security personnel, and thus discouraging theft and other undesirable activities. Payment off board also is more comfortable than juggling change within a moving vehicle.

The main disadvantage to off-board fare collection is the need to construct and operate off-board fare facilities. Fare vending machines, fare sales booths, fare verification devices, and turnstiles all require both investment and physical space. In a BRT system with limited physical space for stations in a centre median, accommodating the fare collection and verification infrastructure can be a challenge. Depending on how the fare system is configured, there may be some time loss while paying off board, whereas paying on board theoretically means that the payment time occurs while the bus is moving. Of course, this type of activity can create safety issues if the driver is both handling fares and driving at the same time. Customers can also be uncomfortably jostled about when trying to pay at the same time the vehicle is accelerating.

Some systems employ a reservoir area within the vehicle to hold passengers while they go through the fare payment and verification process (Figure 8.19). This system is utilised in Brazil to allow the passenger queue to quickly file into the vehicle, which can then accelerate to the next station without waiting for passengers to complete the fare verification process. However, this technique often requires on-board fare collection staff, which in turn raises operational labour costs.

8.3.1.3 Decision-making criteria

There is no one precise point at which a system's capacity will determine if on-board or off-board fare collection is more cost effective. Much depends on demand figures from individual stations, station physical configurations, and average labour costs. However, the advantage of off-board payment clearly increases as the level of boardings and alightings at the station increases. In Goiânia (Brazil) the local public transport agency estimates that an off-board fare system is cost justified when the system capacity reaches 2,500 passengers per hour per direction. The development of a cost-benefit analysis may help determine this capacity point, provided the costing data is available. Figure 8.20 provides an example of this type of analysis.

8.3.2 Platform level boarding

To further reduce boarding and alighting times, most state-of-the-art BRT systems have introduced ***platform level boarding***. With platform level boarding, the stopping bay platform is designed to be the same height as the vehicle floor. This allows for fast boarding and alighting, and also allows easier access for the persons in wheelchairs, parents with strollers, young children, and the elderly.

There are currently two different types of platform level boarding techniques. In one case, a gap exists between the platform and the vehicle. The gap may range from approximately 4 centimetres to over 10 centimetres, depending in the accuracy of the vehicle alignment process. Alternatively, a vehicle can employ a boarding bridge which physically connects the vehicle to the platform. The boarding bridge consists of a flip-down ramp that is attached to the vehicle's doors. As the doors open, the boarding bridge is released and covers the enter gap area between the vehicle and platform (Figures 8.21 and 8.22).

Both techniques, gap entry and boarding bridge entry, have their advantages and disadvantages. Cities such as Curitiba and Quito have experienced much success with boarding bridges. A typical boarding bridge is 40 to 50 centimetres in width, meaning that the vehicle only needs to align within about 35 to 45 centimetres of the platform (Figure 8.23). Thus, there is much more room for error using the boarding bridge.

The boarding bridge also provides boarding and alighting passengers with greater confidence in placing their steps. The confidence means that customers will not have to look down at a gap to judge safe foot placement. Instead, customers confidently march forward. The small act

Fig. 8.19

In Brazil, a "reservoir" space is provided within the vehicle where passengers queue to verify their fare. With the use of this reservoir, the vehicle is able to proceed even before all passengers have verified their fare.

Photo courtesy of the Municipality of Goiânia.

Fig. 8.20

Cost-benefit analysis of external fare collection.

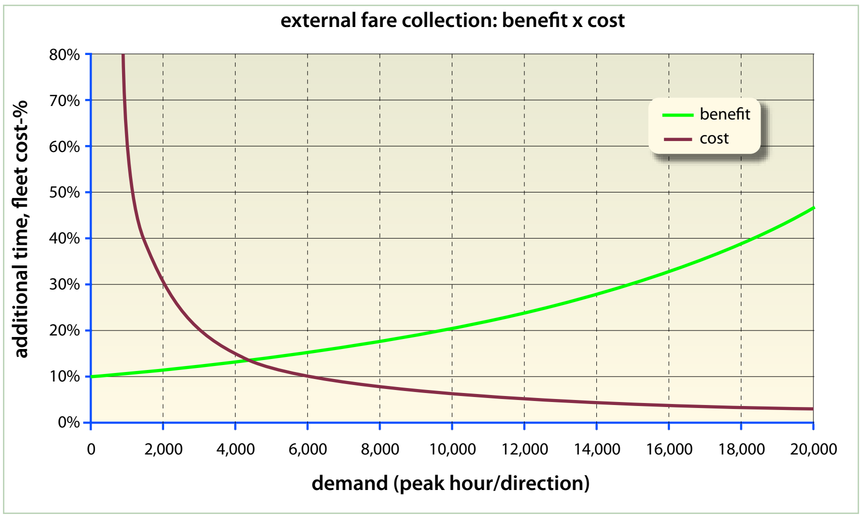


Fig. 8.21 and 8.22
Systems in cities such as Curitiba (left photo) and Guayaquil (right photo) utilise a boarding bridge between the vehicle and platform to facilitate easy boarding and alighting.
Left photo courtesy of Volvo
Right photo by Lloyd Wright

of looking down slows each person's boarding and alighting time. While this lost time seems small on a per passenger basis, the cumulative effect across all passengers can be quite significant. The added customer confidence with the boarding bridge also means that two persons can board or alight side-by-side. When a gap is present, passengers are less likely to board simultaneously. The uncertainty imposed by a gap means customers are less likely to handle both the placement of the foot and the distance beside another passenger at the interface point. A boarding bridge also is significantly more user-friendly to passengers with physical disabilities, wheelchairs, and strollers.

Despite these benefits, the boarding bridge does bring with it a few disadvantages. The added cost of the boarding plate and the pneumatic system to operate it does imply a modest increase to vehicle costs. As a moving part, the boarding bridge also introduces additional maintenance issues and the potential for malfunction. There is also one aspect of the boarding bridge that does not hold a time advantage. The deployment of the bridge itself takes about 1.5 seconds. Likewise, the retrieval of the boarding bridge at departure also requires about 1.5 seconds. While this deployment and retrieval roughly coincides with the opening and closing of the doors, it may introduce a slight delay to the boarding and alighting process. However, overall, the other efficiency advantages of the boarding bridge tend to more than compensate for the deployment and retrieval time.

In contrast to Curitiba and Quito, cities such as Bogotá, Goiânia, and Jakarta elected to forgo use of a boarding bridge. These systems instead permit the existence of a physical gap between the vehicle and the platform (Figures 8.24 and 8.25). Bogotá's TransMilenio system opted not to utilise a boarding bridge principally in order to save the seconds needed to deploy and retrieve the flip-down device. Likewise, the lack of a boarding bridge slightly reduces vehicle costs and maintenance costs.

Fig. 8.23
The presence of the boarding bridge means that the driver does not need to be as precise docking at the platform. In turn, this can significantly reduce the time lost at stops.
Photo by Lloyd Wright

Fig. 8.24
A gap entry system is employed in Goiânia (Brazil).
Photo by Lloyd Wright

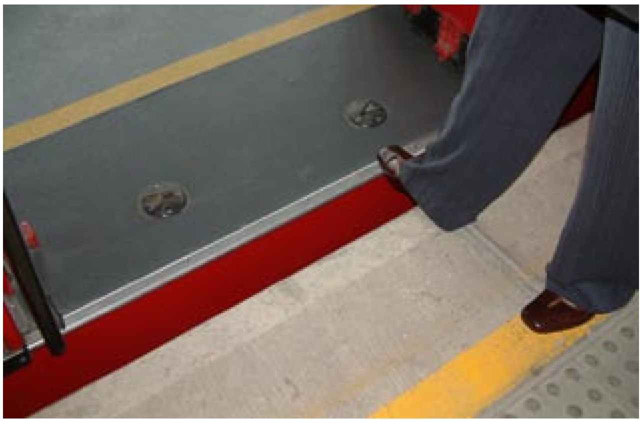


Fig. 8.25
If the vehicle can be aligned to the platform within 10 cm, then customers can safely board and alight with a gap entry.
Photo by Lloyd Wright

While cities such as Bogotá do gain time lost to ramp deployment, time can be lost elsewhere. Depending upon the width of the gap, passengers will tend to look down and hesitate slightly. Further, passengers have a greater tendency to depart the vehicle one-by-one when a gap exists between the vehicle and the platform. A wide gap can also introduce a significant safety and liability risk. If a passenger missteps and falls through the gap, a serious injury can occur. Those passengers with disabilities, wheelchairs, and strollers will not only take longer to cross a gap but may have physical difficulty in doing so. The extremely wide gap occurring with the TransJakarta system is detrimental both to system performance and customer safety (Figure 8.26).

Since a gap entry requires the vehicle to get as close to the platform as possible, there may also be delays in the vehicle acceleration and deceleration process. The driver will need to be more careful in approaching and departing the platform. Clearly, it is simpler to dock the vehicle at a maximum distance of 45 centimetres rather than a distance of 5 or 10 centimetres.

8.3.3 Vehicle acceleration and deceleration

The time required for a vehicle to approach and then accelerate away from a stopping bay is also part of the equation for calculating the efficiency of stops. If conditions require a slow, careful approach to the stations, overall speeds and travel times will suffer. The time consumed in the deceleration and acceleration process is affected by the following factors:

- Type of vehicle-platform interface;
- Use of docking technology;
- Vehicle weight and engine capacity;
- Type of road surface;
- Presence of nearby at-grade pedestrian crossings.

As noted above, the vehicle acceleration and deceleration time is greatly influenced by the closeness in docking required. Use of a boarding bridge requires drivers to only dock within 45 centimetres of the platform. By contrast, the close precision required to achieve a gap of only 5 or 10 centimetres will slow this alignment process. Manual alignment contributes to both slower docking time as well as greater variability

Fig. 8.26
The substantial gap between the vehicle and platform in Jakarta can be a significant safety risk to customers.
Photo courtesy of ITDP

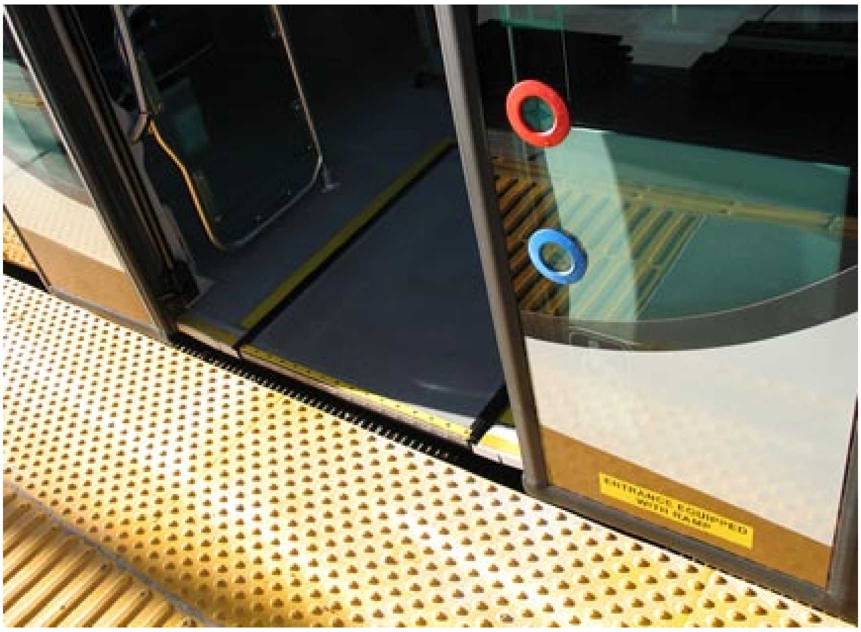


Fig. 8.27
When operating properly, the optical guidance system employed in Las Vegas can align the vehicle within a few centimetres of the platform.
Photo courtesy of NBRTI

in docking distances. Manual alignment can be improved somewhat through use of optical targets for drivers along the face of the station. Mirrors can also be utilised to improve the accuracy of manual targeting.

Alternatively, there are automatic docking technologies that can increase the speed and accuracy of vehicle to platform alignment. Mechanical, optical, and magnetic docking technologies can all be applied for this purpose. In each of these cases, the vehicle is automatically guided into platform position without any intervention from the driver.

Mechanical guideway systems, such as those utilised in Adelaide, Essen, Leeds, and Nagoya, physically align the vehicle to the station through a fixed roller attached to the vehicle. In these cities, the fixed guideway is utilised both at stations and along the busway. However, a city could elect to only utilise the mechanical guidance at the station. Bangkok is currently considering use of mechanical guidance only at stations. A mechanical guidance system is likely to deliver a rapid alignment within a vehicle to platform distance of seven centimetres.

Optical docking systems operate through the interaction between an on-board camera and a visual indicator embedded in the busway. Software within the on-board guidance system then facilitates the automated steering of the vehicle. The Las Vegas MAX system has attempted to make use of this type of technology (Figure 8.27). Problems have occurred, though, due to the inability of the optical reader to function properly when the roadway is wet. Undoubtedly the early difficulties with this technology will be improved upon as more cities continue with experimentation.

A magnetic guidance system works on a similar principle to that of an optical system, but with magnetic materials placed in the roadway as the location indicator. The Philaeus bus, as utilised in the Eindhoven BRT system, is capable of magnetic guidance.

Optical and magnetic guidance systems produce a highly precise degree of docking. However, due to current limitations with these technologies and their software, required deceleration

Table 8.4: Observed boarding and alighting times for different configurations

Configuration characteristics				Boarding and alighting times	
Fare collection method	Doorway width (metres)	Stairway boarding or level boarding	Vehicle floor height	Observed boarding time	Observed alighting time
On-board, manually by driver	0.6	Stairway	High	3.0[1]	NA
On-board, contactless smart card (no turnstile)	0.6	Stairway	High	2.0[2]	NA
Off-board	0.6	Stairway	High	2.0[3]	1.5[3]
Off-board	0.6	Stairway	Low	1.5	1.2
Off-board	1.1	Stairway	High	1.5	1.0
Off-board	1.1	Stairway	Low	1.1	0.9
Off-board	1.1	Level	High	0.75[1]	0.5[1]

1. Colombia, Mexico, 2. China, 3. Brazil, NA – Not available

and acceleration speeds can actually be slightly less than manual techniques. Further, the added hardware and software costs of an optically automated system can push vehicle costs well over US$ 1 million each.

8.3.4 Doorways

All the efforts applied to vehicle size, station design, and docking systems can be lost if the vehicle's doorways inhibit smooth passenger flows. The size, number, and the location of the doorways all play a role in facilitating efficient boarding and alighting. The most successful BRT systems have employed wide, multiple doorways to ensure platform bottlenecks are avoided. The combination of at-level boarding and wide, multiple doorways can reduce boarding and alighting times per passenger by between 0.25 seconds (down to 0.75 seconds) and 0.50 seconds in ideal conditions

For the 160-passenger articulated vehicle, four sets of double doors is becoming the standard configuration. Each double door is typically 1.1 metres in width. Each door thus allows two persons to simultaneously enter and/or exit the vehicle. Table 8.4 compares actual observed boarding and alighting times for different combinations of doorway and platform configurations.

From Table 8.4, it can be seen that a wide doorway (1.1 metres) with level platform boarding generates the most efficient boarding and alighting times. Bogotá's TransMilenio system with its four sets of 1.1 meter wide doors has recorded boarding times in the area of 0.3 seconds per passenger.

Providing several doorways dispersed along the length of the vehicle multiples the capacity of the boarding and alighting process. Multiple doorways improve boarding and alighting efficiency for two reasons: 1. Increased capacity; 2. Reduced passenger congestion. When there is only one doorway, passengers will tend to cluster in a congested manner (Figure 8.28). The subsequent jostling for position and conflicts between entering and exiting passengers will swell total boarding and alighting time. The presence of multiple doorways diminishes the occurrence of these types of bottlenecks.

The maximum theoretical reduction in boarding and alighting time for door width would be a vehicle with its side entirely open. In such a situation, passengers could enter and exit at all points at once. Such a vehicle could be filled to capacity in only 10 seconds. A vehicle of this type would be very useful at high-demand stations during peak hours.

However, in reality there are relatively sharp diminishing returns for each additional door after four. This finding probably accounts for why today four sets of 1.1 metre doorways has become the standard for articulated vehicles. In this configuration, 27 percent of the vehicle's length is dedicated to doorways. This arrangement also occurs for practical, physical reasons. Doorways cannot be located in the driver's space, above wheel wells, or along the articulation structure. Further, additional increases in doorway area may lead to a structural weakening of the vehicle. Figure 8.29 illustrates the relationship between the number of doorways and the average boarding and alighting time per passenger for the case of Brazilian cities.

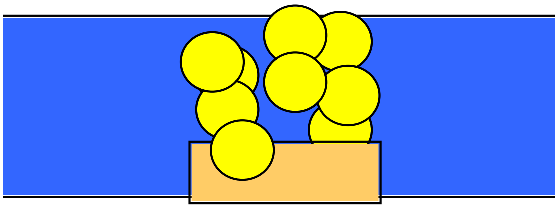
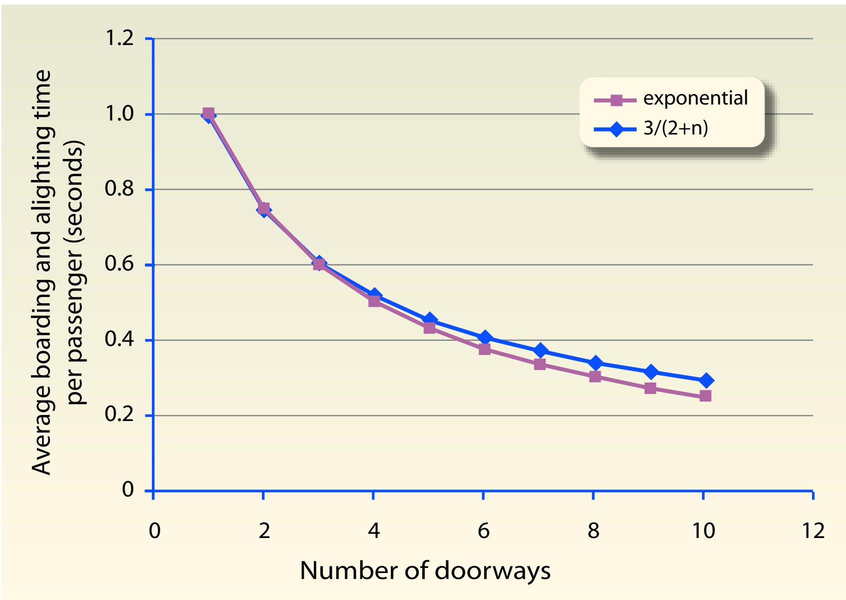


Fig. 8.28
Vehicles employing a single doorway almost invariably encounter customer congestion in attempting to board and alight.
Image courtesy of Pedro Szasz

Fig. 8.29
Impact of the number of doorways on boarding and alighting times.



Doorway efficiency can also be closely tied to the vehicle load factor and interior design. Once load factors exceed 85 percent, the area around the doorway will become exceedingly congested. Standing passengers will have little choice but to stand in this area, and thus reducing the effective door width (Figure 8.30). Passengers standing in this area may have to temporarily step off the vehicle to allow some passengers to alight. The fact that these persons must endure multiple boardings and alightings will diminish both customer satisfaction as well as operational efficiency. Likewise, the interior design and the amount of open space around the doorway area will determine the efficiency of customer movements. In extreme conditions, customers may miss their intended stations due to the inability to manoeuvre towards the doorway.

The directional conflict between boarding and alighting passengers will lead to delays, especially in peak periods. Alighting passengers are typically given priority over boarding passengers. However, the effectiveness of such a policy depends greatly upon cultural norms. Educating passengers to queue properly and show courtesy to alighting passengers can be difficult in some situations.

One solution to this conflict is designating some doorways as entry only and others as exit only. Curitiba utilises this technique in some of its stations. This directional designation can improve boarding and alighting efficiency, but it can also cause customer confusion. Unless doorways are clearly denoted as exit or entry areas, customers may unwittingly use the wrong doorway. Further, if only two out of four doorways are available for alighting, customers will have more distance to cover in order to access an exit. In turn, this situation creates more jostling within the vehicle from customers seeking to make their way towards a doorway designated for alighting.

Consideration of doorway location and distribution should also be part of the design process. In general, it is most efficient to distribute doorways as widely as possible. The distribution of doorways permits customers to readily access an exit as a vehicle stops. If doorways are poorly distributed, customers may be forced to jockey for an exit position well before the vehicle nears the station. This sort of forced positioning by customers can make the public transport journey considerably less pleasant. As noted earlier, though, doorway location is constrained by the location of the driver's area, the wheel wells, and the articulation structure. Doorways at the extreme front or rear of the vehicle tend to reduce efficiency since alighting can only occur from a single direction.

Fig. 8.30
The overcrowding of vehicles results in delayed boarding and alighting due to customer congestion around the doorway.
Photo by Carlos F. Pardo

Fig. 8.31 and 8.32
The use of a single doorway in Jakarta has greatly limited the viable capacity of the system.
Left photo by Lloyd Wright
Right photo by Shreya Gadepalli (ITDP)

The capacity of the Jakarta BRT system is largely inhibited due to the decision to utilise only a single doorway (Figures 8.31 and 8.32). The system's current peak capacity is only approximately 2,700 passengers per hour per direction. TransJakarta's capacity limitations are actually due to several design and operational problems, including:

- Single doorway;
- Standard-sized vehicle;
- Large open gap between vehicle and platform;
- Presence of conductor partially blocking doorway entrance.

As a solution to its capacity constraints, TransJakarta elected to increase its vehicle fleet by adding 36 buses to its existing fleet of 54 buses. However, only about 8 of these buses actually helped increase capacity before bus queuing at the stations dropped the level of service down to unacceptable levels.

Table 8.5 presents TransJakarta's present situation along with potential solutions to its capacity problems. Shifting towards an articulated vehicle with wide, multiple doorways would add the most capacity to the existing system.

8.3.5 Station platform

The size and layout of the station platform will have a discernible impact on system capacity and efficiency. In some systems, platform size can even be the principal constraint on overall capacity. For many of the London tube lines, it is the relatively small platform width that ultimately determines the total possible passenger volumes.

The determination of the optimum platform size is based on the number of boarding and alighting passengers at peak periods. If the platform hosts two service directions along one another, then the sum capacity requirements of both directions must be factored into platform sizing. Chapter 11 (*Infrastructure*) details the calculation of platform sizing.

Additionally, the layout of the platform will affect overall efficiency. To the extent possible, clear sight lines and walking paths should be maintained on the platform, especially near boarding and alighting doorways. Thus, any interior infrastructure such as public telephones and plants should be kept away from the doorways. Clear signage can likewise help ensure that optimum passenger movements are achieved.

8.3.6 Summary of vehicle-platform interface

As this section has indicated, improving the efficiency of the vehicle-platform interface can deliver significant dividends in terms of saved boarding and alighting times. Table 8.6 summarises the potential gains that can be achieved by improving the vehicle-platform interface as well as by properly sizing the vehicle. The noted capacity improvements can be achieved

Table 8.5: Scenarios for improving TransJakarta's capacity

Scenario	Average boarding time (seconds)	Capacity (pphpd)	Dwell time (seconds)	Average speed (kph)	Required fleet size (vehicles)
Present situation	2.5	2,700	45	17	60
Improving boarding	1.7	3,700	35	19	56
Vehicle with two doors	0.5	6,000	22	21	51
Articulated vehicle (4-doors)	0.3	9,600	18	23	26

Table 8.6: Impacts of vehicle-platform interface and vehicle size on capacity[2])

Vehicle and operation type	Maximum vehicle capacity	Average dwell time (Td)	Average boarding & alighting time (T1)	Corridor capacity (pphpd)	Vehicle capacity (vehicles/hour)
Mini-bus	15	10	3.0	1,137	76
Midi-bus	35	11	3.0	1,575	45
Standard bus	70	12	3.0	1,867	27
Articulated vehicle with conductor	160	13	1.5	3,777	24
Bi-articulated with conductor	240	14	1.5	4,019	17
Articulated, level platform, conductor	160	13	1.0	5,120	32
Bi-articulated, level platform, conductor	240	14	1.0	5,574	23
Articulated, level platform, off-board	160	13	0.3	9,779	61
Bi-articulated, platform, off-board	240	14	0.3	12,169	51

Source: Steer Davies Gleave

without compromising average vehicles speeds of around 25 kph.

Table 8.6 presents the optimised capacity values for a BRT system operating on a single lane and using a single stopping bay. For this type of scenario, the maximum capacity is approximately 12,000 passengers per hour per direction, assuming off-board fare collection and boarding and alighting with a level platform. Achieving even higher capacities at an acceptable level of service, will require other measures such as multiple stopping bays.

8.4 Multiple stopping bays and express services

"There can be no economy where there is no efficiency."

—Benjamin Disraeli, former British Prime Minister, 1804–1881

8.4.1 Multiple stopping bays

8.4.1.1 Impact on capacity

Measures such as vehicle size, vehicle-station interface, and doorway widths all make a contribution to higher-capacity and higher-speed systems. However, even together, these measures will likely only produce capacities in the range of 12,000 pphpd. Thus, while systems such as those in Curitiba and Quito are high-quality BRT systems, there maximum corridor capacities are limited to this value.

It was not until the year 2000, when Bogotá's TransMilenio was introduced, that an entire new level of capacity was possible. Today, Bogotá achieves a peak capacity of 45,000 pphpd and there are good indications that values as high as 50,000 pphpd or even higher are now possible with BRT.

The main difference between TransMilenio and those systems that preceded it is the number of stopping bays utilised. By increasing the value of the "Nsp" (number of stopping bays) in the capacity equation, Bogotá has allowed BRT to enter a capacity region once thought to only be feasible through rail metro systems.

$$Co = \frac{Nsp * 1{,}440}{\left[\dfrac{Td * (1 - Dir)}{Cb} + (Ren * T1)\right]}$$

In some cases, a single TransMilenio station will host up to five stopping bays (Figure 8.33). As is evident from the corridor capacity equation above, the five stopping bays hold the potential to increase capacity by five times. Each stopping bay represents a different set of services or routes

[2]) The capacity calculation takes into account the expected saturation levels of the stopping bay.

(*e.g.*, local services versus limited-stop services or routes with a different final destination).

The presence of multiple stopping bays serves two distinct purposes. First, the multiple stopping bays permit many different types of services from the same station, such as local services or limited-stop services. Each stopping bay represents a different set of services or routes.

Second, the multiple stopping bays can dramatically reduce the saturation level (the "X" variable in the capacity equation) at the stations. Since station saturation is typically the principal barrier to higher-capacity services, adding stopping bays is perhaps the cornerstone of any proposed system requiring higher capacity levels.

8.4.1.2 Multiple stopping bays and saturation levels

As noted earlier, to maintain a high level of service, saturation levels should be 40 percent or below. If saturation is over 0.40, a second lane and a second stopping bay are likely to be required. As saturation increases, more stopping bays will likely be needed.

In order to maintain a saturation factor of less than 0.40, services at each stopping bay must be properly scheduled and spaced to limit congestion. A saturation factor of 0.40 corresponds to approximately 60 vehicles per hour, but the specific stopping bay demand can reduce or increase this value. If 18-metre articulated vehicles are utilised, then 60 vehicles per hour corresponds to an approximate capacity of 9,000 pphpd, and this figure is a general limit for one lane simple operation. Since a lane will begin to congest once 70 vehicles per hour per direction is reached, a second stopping bay is recommended whenever volumes exceed this level.

The saturation level for an individual stopping bay can be calculated as in Equation 8.10.

Equation 8.10 Calculating the saturation level of a stopping bay

$$X = Td * F + [(Pb * Tb) + (Pa * Ta)]$$

Where:

X = Saturation level at a stopping bay
Td = Dwell time (seconds)
F = Frequency (vehicles per hour)

Fig. 8.33
The use of multiple stopping bays has been one of the principal reasons Bogotá is able to achieve very high passenger capacities.
Photo courtesy of Akiris

Pb = Total number of passengers boarding (passengers)
Tb = Average boarding time per passenger (seconds)
Pa = Total number of passengers alighting (passengers)
Ta = Average alighting time per passengers (seconds)

This equation simply shows that the saturation level "X" is a function of the total dwell time per hour plus total of the passenger boarding and alighting times. Box 8.1 provides a comparison of stopping bay saturation levels for two different situations.

8.4.1.3 Route distribution along multiple stopping bays

Multiple stopping bays imply the existence of multiple routes emanating from a single station. A question arises as to the distribution of the routes within the physical structure of the station. In other words, which routes should be grouped near one another and which routes can be separated by a longer walk for the customer?

The guiding principle should be based upon customer convenience. Ideally, the right distribution of routes along the stopping bays should minimise the walking distance covered by the largest majority of customers. Thus, the most common transfers should be grouped together.

Box 8.1: Examples of saturation levels for individual stopping bays

Saturation levels at a given stopping bay will vary considerably depending on the passenger demand and vehicle frequency. In the case of most developed-nation bus services, saturation levels are typically quite low. For example, for London bus service along the city's Oxford Street, the total dwell time per bus is 11 seconds, and the frequency is 24 buses per hour. An average total of 16 persons board or alight in a given hour, with each boarding and alighting requiring roughly three seconds each.

The saturation level is therefore calculated as follows:

X = (11 seconds * 24 buses per hour) + (3 seconds * 16 passengers)
 = 312

Because frequencies are given in hours and dwell times, boarding times, and alighting times are given in seconds, 312 must be divided by 3600. Thus,

X = 312 / 3,600 = 0.09

This value is a very low saturation rate. At this level of bus flow, there is no problem with congestion at the stopping bay.

By contrast, BRT systems operated along high-capacity corridors will typically experience considerably higher saturation levels. Table 8.7 records values for a hypothetical BRT corridor served by a single stopping bay.

Table 8.7: Components to saturation level at a stopping bay

Flow components		Time components			Saturation level
Factor	**Value (units / hour)**	**Factor**	**Value (seconds)**	**Value (hours)**	**Flow + Time**
Frequency (F)	90	Dwell time (Td)	12	0.00333	0.3000
No. of boarding passengers (Pb)	400	Boarding time (Tb)	3	0.00083	0.3333
No. of alighting passengers (Pa)	300	Alighting time (Ta)	2	0.00056	0.1667
				Total	0.8000

Table 8.7 highlights the individual contribution that each component makes to the overall saturation level. In this case, the sum of the components totals a saturation level of 0.8, which is exceedingly high. A saturation level of this magnitude will almost certainly produce busway congestion and thus reduce average vehicle speeds. At this level of saturation, it is clear that a second stopping bay should be added.

This philosophy will not only improve customer convenience but it will also improve overall station capacity. If large numbers of passengers are forced to criss-cross the length of the platform area, then passenger congestion will ensue. This congestion can subsequently have a negative impact on station capacity, dwell times, and the overall performance of the corridor.

Often, the greatest efficiency in stopping bay distribution can be gained by placing together routes which have destinations in relative geographical proximity to one another. This geographical clustering of routes may take two different forms:

1. Routes with adjacent geographic coverage (Figure 8.34);
2. Routes shared by two different types of services (such as local and limited-stop services) covering a similar corridor (Figure 8.35).

If frequencies are sufficiently spaced, some routes can even share the same stopping bay area. For example, a local service and a limited-stop service could share the same stopping bay if the frequency levels made a simultaneous arrival unlikely. However, in such instances, sufficient space should be reserved for a vehicle to wait behind the stopping bay, in case both routes arrive consecutively. The advantage of a shared stopping bay is that passengers changing from a local service to a limited-stop service (or vice versa) are not forced to walk to a different platform area. However, if different routes share a stopping bay, the risk of customer confusion increases. While vehicle route numbering, vehicle colour-coding, platform display messages, and platform audio announcements can all help to minimise such confusion, some passengers may unwittingly board the wrong vehicle.

8.4.1.4 Passing lanes

In order for multiple stopping bays to function properly, and for services to be split between various local and limited-stop routes, vehicles must be able to pass one another at the stations. Therefore, multiple stopping bays should be accompanied by a passing lane at the station (Figure 8.36). The second busway lane at the station stop allows vehicles to pass one another in accessing and exiting the correct bay.

The passing lane may exist as just a second lane in the station area, or the additional lane may be extended all along the corridor (Figures 8.37). Whether the second lane is needed beyond the station area depends upon the saturation levels along the corridor, and especially depends upon the level of congestion at intersections.

The principal difficulty in including a passing lane is the impact on road space. The additional lane in each direction would seem to require a road width few developing cities can reasonably provide. However, a staggered station design can help to permit passing lanes, even in relatively tight corridors. In this case, the sub-stops for each direction of travel are offset. The preferred median station design is retained, but its shape is elongated to help accommodate the passing lane. Passengers can still change directions within

Fig. 8.34
Platform order based on geographic proximity of routes.

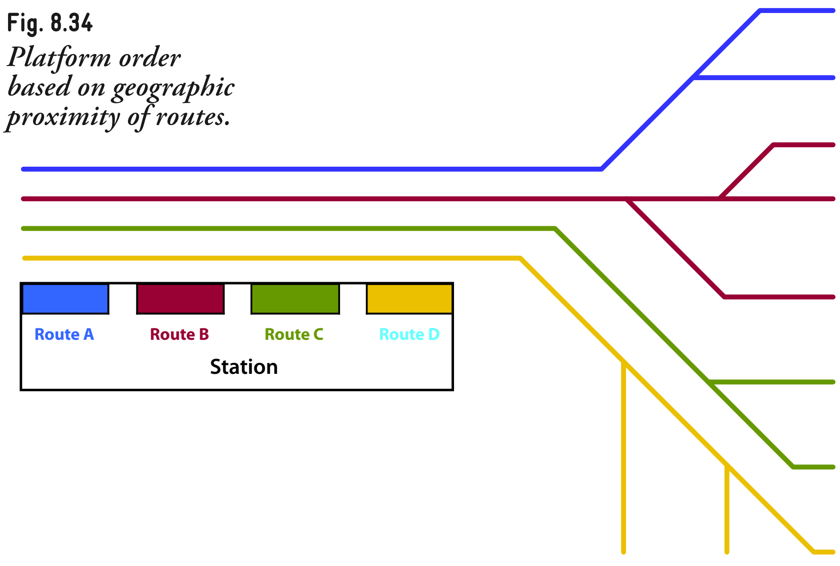


Fig. 8.35
Platform order based on service clustering.

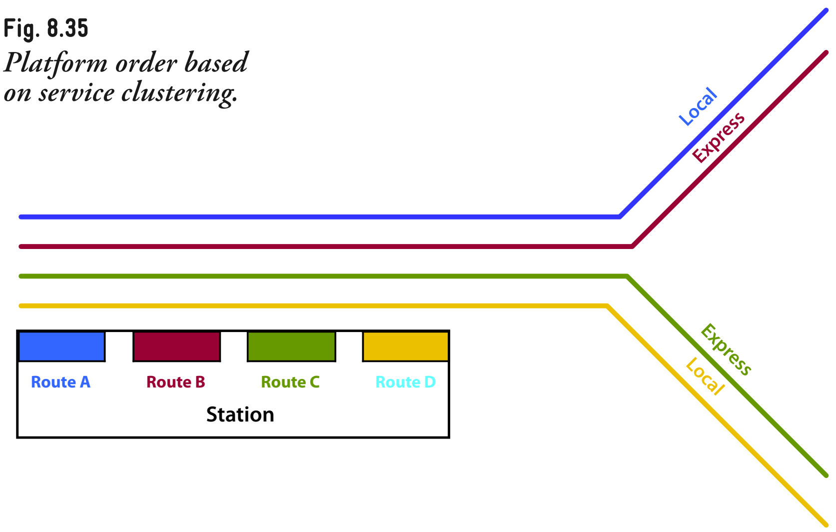


Fig. 8.36
The existence of a passing lane makes the high passenger capacities achieved in the Bogotá system possible.
Photo by Carlos F. Pardo

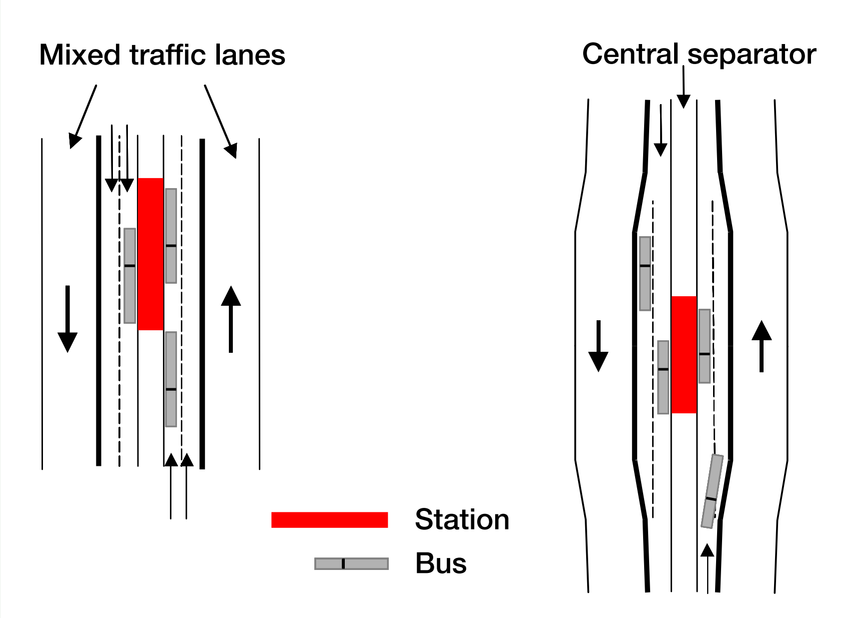


Fig. 37
Options for provision of a passing lane

the closed station area by crossing a connecting platform. In this case, the higher passenger flows within the stations are achieved by lengthening the stations instead of widening them.

Other options for accommodating passing lanes in relatively narrow roadways include reducing mixed traffic lanes as well as making property purchases for widening. In some BRT cities, such as Barranquilla (Colombia), plans call for the purchase of properties near station areas. The road infrastructure is widened in these areas in order to accommodate the passing lane. This same strategy is being proposed for some stations of the Dar es Salaam system (Figure 8.38). The viability of property purchases for this purpose depends upon local property costs as well as the existence of a well-designed compensation programme for property owners.

8.4.2 Capacity impacts of limited-stop and express services

8.4.2.1 Impact on corridor capacity

Related to the availability of multiple stopping bays, limited-stop and express services can also help to significantly expand corridor capacity. The provision of express and limited-stop services can do much to prevent vehicle congestion at stations. Since these services avoid the need for vehicles to stop at each station, the overall congestion level is reduced.

Within the corridor capacity calculation, the provision of limited-stop and express services affects the term "1 – Dir":

$$Co = \frac{Nsp * 1{,}440}{\left[\dfrac{Td * (1 - Dir)}{Cb} + (Ren * T1)\right]}$$

Box 8.2 provides an example of the potential impact of limited-stop services on corridor capacity.

8.4.2.2 Determining the number of routes

Optimising the number and location of local, limited-stop, and express routes within a traffic

Fig. 8.38
In order to accommodate passing lanes at stations of the proposed Dar es Salaam system, road widening is envisioned.
Image courtesy of the Dar es Salaam Rapid Transit system (DART)

Box 8.2: Increasing capacity with limited-stop services

In the corridor capacity calculation, the term "Dir" represents the percentage of vehicles that operate either limited-stop or express services. In the case of TransMilenio, approximately 50 percent of the vehicles serve these type of routes.

Using the following inputs, the capacity benefit of limited-stop services can be calculated:

Number of stopping bays (Nsp) = 3

Vehicle length (L) = 18 metres

Dwell time (Td) = 10 + L/6 = 13 seconds

1 – Dir (percent of limited-stop services) = 1 – 0.5 = 0.5

Average dwell time for limited-stop services = 13 * 0.5 = 7.5

Vehicle capacity = 160 passengers

Renovation rate = 0.25

Average boarding and alighting time per passenger = 0.3 seconds

$$\textbf{Corridor capacity (Co)} = \frac{3 * 1{,}440}{\left[\dfrac{(10 + 18/6) * (1 - 0.5)}{(10 * (18 - 3)} + (0.25 * 0.3)\right]}$$

$$= \textbf{35,446 pphpd}$$

If the value for "Dir" was zero (i.e. no limited-stop services), then the capacity for this corridor would be reduced to 26,721 pphpd, a 25 percent drop from the scenario with limited-stop services.

The calculated capacity of 35,466 pphpd is close to the actual capacity of TransMilenio today. With this formula, most of the secrets to TransMilenio's capacity and speed performance become clear.

model is not a simple matter. The following list presents some general rules for this optimisation process:

1. Saturation at the station should not surpass its operational capacity, specifically calculated as: Saturation = 0.4 x number of sub-stops.
2. Stations with less demand should have fewer routes stopping.
3. Transfers between limited-stop and local services will significantly affect station congestion and vehicle dwell times. The selection of the appropriate stations to facilitate such transfers will help to control the station congestion levels.
4. Both directions of a route should produce roughly the same demand. To obtain this equilibrium, the opposite pairs need to be adequately chosen.
5. The set of stations served by a particular route may be geographically based (connecting a group of continuous stations) or demand base (connecting the highest demand stations). Connecting many high-demand stations seems attractive, particularly from a customer standpoint. However, one must be careful to avoid an excessive concentration of transfer demand at the highest-demand stations.
6. The stations with more demand for boarding and alighting should have more routes stopping in order to minimise transfers for the majority of passengers.
7. Routes with more demand should stop less, and thus be provided with more limited-stop and express options. If a local route has more demand than a limited-stop route along the same corridor, then the limited-

stop route should stop at more stations in order to increase its demand.

8. Routes should have peak frequencies ranging from 10 to 30 vehicles per hour (*i.e.,* headways ranging from 2 to 6 minutes), although systems such as TransMilenio are capable of having as many as 60 vehicles per hour on a single route. If the required frequency is higher than 30 vehicles per hour, the route can be divided into two. If the frequency is lower than 10 vehicles per hour, then the route should be joined with another.
9. In order to avoid large concentrations of transfers at high-demand stations, it may be useful to stop many routes at a nearby small station, so users can transfer there.
10. The size of the required vehicle fleet, travel times, waiting times, and transfer locations are the key variables in the simulation process for optimising the routing of local, limited-stop, and express services.

The best mechanism for optimising the number of routes and the split between local, limited-stop, and express services is through a public transport simulation model. Software packages such as EMME2, Transcad, Visum, and others are well suited for this purpose. The chosen software package must contain the origin-destination (OD) matrix for public transport trips, and must include a compartmental model in which each passenger has multiple corridor and route choices based on the generalised cost of the total trip, including waiting times.

However, a rapid calculation technique can provide a first approximation for the total number of routes. The base equation for this calculation is as follows:

Equation 8.11 Calculating the optimum number of routes

$$\mathbf{NR} = 0.06 * (30 * 150)^{0.5} = 4.0 \text{ routes}$$

Where:

NR = Optimum number of routes

NS = Number of stations along corridor (in one direction)

F = Frequency (vehicles per hour)

Thus, for a corridor with a total of 30 stations (NS = 30) and a frequency of 150 vehicles per hour (F = 150), the approximate optimum number of routes is calculated as:

In this case, planners may elect to develop two different local services and two different limited-stop services. Alternatively, the corridor could host a single local service along its entire length, two limited-stop services, and an express service.

8.5 Convoying

"Even if you are on the right track, you will get run over if you just stand there."

—Will Rogers, social commentator and humorist, 1879–1935

In general, multiple stopping bays are coupled with passing lanes in order to allow vehicles to overtake one another and thus readily access the appropriate stopping bay. As Chapter 5 (*Corridor selection*) has noted, there are also design options that permit passing lanes even when right-of-way space is limited.

However, there may be circumstances when either political conditions or roadway space simply will not permit the development of a passing lane. If the capacity requirements along the corridor require multiple stopping bays, there is still an option to do so without a passing lane. In this case, some of the benefits of separate stopping bays can be achieved through the "convoying" or "platooning" of the vehicles. A convoy system permits multiple stopping bays but without a passing lane.

8.5.1 Overview of convoying systems

Convoys involve two or more vehicles operating along the busway in a closely bunched pack. In some respects, a convoy system is similar to an extended set of rail cars. The order of the vehicles is typically set so that the first vehicle stops at the far stopping bay and the next vehicle stops at the subsequent stopping bay (Figure 8.39). In this case, each stopping bay represents a different service or a different route. In other cases, multiple vehicles within the convoy may actually be serving the same route. For this situation, the convoy is simply adding vehicle capacity to a single route.

A single lane operating with a single stopping bay per station can achieve a corridor capacity of

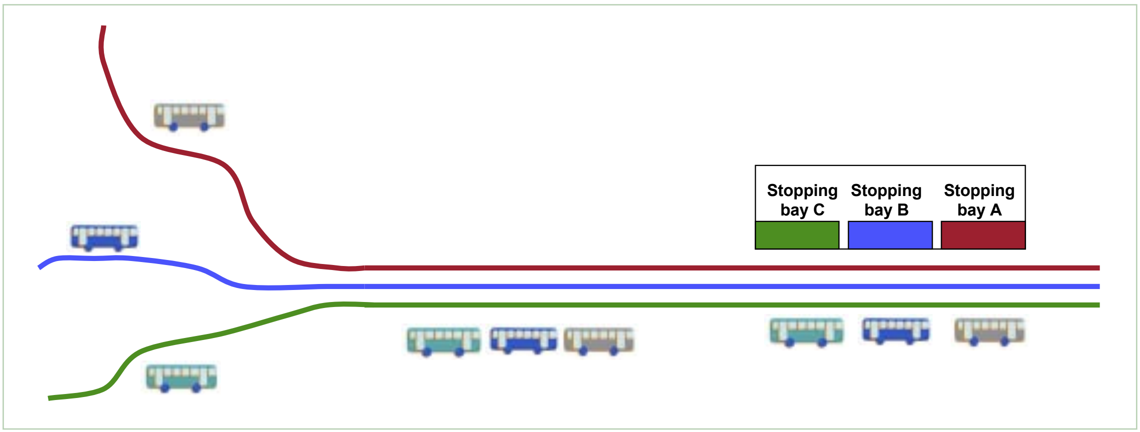


Fig. 8.39
Convoying systems work by permitting multiple routes to come together as a "train" of vehicles along a trunk corridor.

approximately 9,000 pphpd. Convoys can increase capacity by around 50 percent to a maximum of 13,000 pphpd without any reduction in the level of service. For demand volumes over this level, multiple stopping bays and passing lanes are necessary. However, some systems utilising convoying systems have achieved corridor capacities over 20,000 pphpd. Both the "Farrapos" and the "Assis Brasil" corridors in Porto Alegre reach peak capacities of over 20,000 pphpd through convoying techniques (Figures 8.40 and 8.41). Nevertheless, the penalty for extending convoying to this level is a reduced level of service in terms of average speed.

A convoy system could also be possible on systems which have passing lanes at some but not all stations. In such a case, lower-demand stations with a single stopping bay would utilise a passing lane. At higher-demand stations, where all routes would be stopping, then the vehicles would stop as a convoy in a set order.

Systems may operate as ordered convoys or non-ordered convoys. In an ordered convoy, the vehicles must approach the station in a set order so that the vehicles stop in the designated stopping bay. Signage at the station instructs passengers which stopping bay corresponds with their intended route. To manage and control the order of the vehicles entering the busway, a control centre in conjunction with automatic vehicle locating (AVL) technology may be essential. Communications between the control centre and the drivers allows each vehicle to adjust its position in order to enter the busway at the right moment.

In a non-ordered convoy, the vehicles approach the station in any order, depending on the timing of each vehicle's entry into the main busway. In this case, customers will not know at which stopping bay their intended route will stop. However, visual displays or audio announcements may indicate the stopping bay number shortly before a vehicle's arrival.

8.5.2 Disadvantages of convoys

Unfortunately, the convoying or platooning of vehicles is quite difficult to manage and control. The vehicles must enter the busway in the appropriate order or there will be considerable delays and backing up of vehicles. Further, since passenger boardings will vary for different vehicles, the dwell times will also vary. Some vehicles may needlessly wait behind others while a longer boarding takes place. Thus, in a convoy system the slowest vehicle will likely set the speed for the entire fleet. For these reasons,

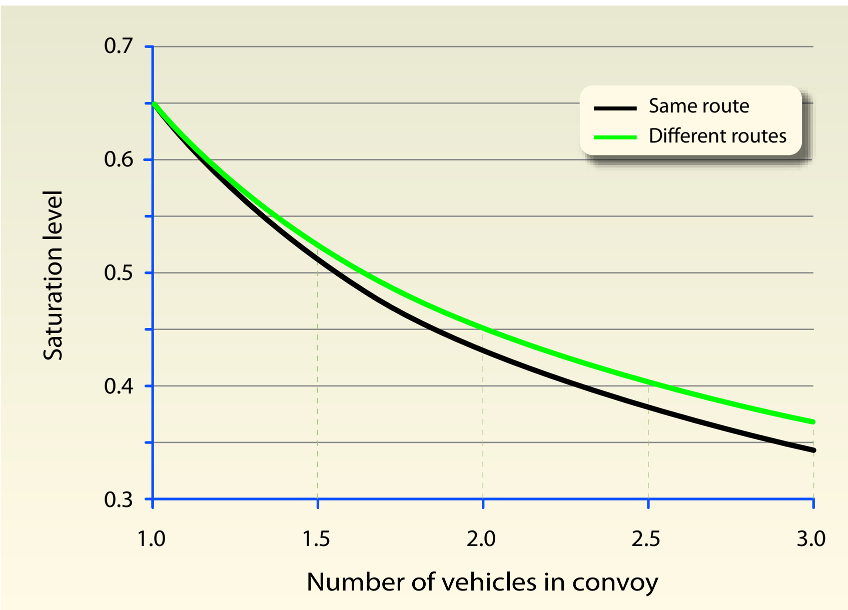
Fig. 8.40 and 8.41
Convoying allows the Porto Alegre system to achieve peak capacities of over 20,000 pphpd, but at the same time this technique can result in busway and station congestion and therefore slowing average vehicle speeds.
Photos by Lloyd Wright

Fig. 8.42
Despite Porto Alegre's system being a premium public transport service along a dedicated busway, customers are sometimes forced to flag down their desired vehicle.
Photo by Lloyd Wright

multiple stopping bays are probably best implemented through the provision of passing lanes at stations.

Non-ordered convoys will typically add further stress and confusion to a customer's journey. In non-ordered systems, the customers may not know at which stopping bay their route will be arriving. Even if announcements give customers a brief warning, there is still likely to be some confusion. This situation implies that customers may be running from one end of the station to the other in search of their intended vehicle. Rather than spending one's waiting time doing another value-added activity, such as reading or relaxing, a non-ordered convoy forces customers to stand at ready alert in search of their vehicle. In some cases, passengers may be forced to flag down the desired vehicle in order for the vehicle to actually stop (Figure 8.42).

Fig. 8.43
Impact of convoy length on saturation levels



8.5.3 Convoys and saturation levels

The number of stopping bays necessary at each station is a function of the number of boarding and alighting passengers. For a low-demand station on an otherwise high-demand corridor, only a single stopping bay may be necessary. However, in this instance, a passing lane would be recommended. In circumstances with high levels of boarding and alighting passengers, systems have used as many as five stopping bays to accommodate the demand.

Convoys can be partially defined through two factors: 1. Average number of vehicles per convoy (m); and 2. A constant that defines the degree of similarity between the routes of the different convoy vehicles (Kc). The constant "Kc" must take on a value between one and two. If all vehicles in the convoy serve the same route, as if the convoy was a train, then Kc is equal to one. If all vehicles in the convoy serve different routes, then Kc is equal to two. The dwell time within a convoy system is defined by the following equation:

Equation 8.12 Dwell time within a convoy system

$$Td = (10 / m) + (L / 4)$$

Properly managed and controlled convoys should theoretically produce reductions in saturation levels. Box 8.3 compares saturation levels for a system with and without convoying. However, the difficulty in managing and controlling a convoy quite often implies that saturation levels can actually increase.

In general, as the number of vehicles in the convoy increase, the theoretical saturation level will tend to decrease. Figure 8.43 illustrates this relationship.

As Figure 8.43 indicates, saturation levels for convoys with all vehicles serving the same route are slighting better than the saturation levels for convoys with vehicles serving different routes. However, this difference is marginal. As noted, though, the experience of convoys to date has not met its theoretical promise. The difficulty in controlling vehicle entry to the convoy means that convoys can frequently suffer from congestion at stations. Additionally, the confusion created amongst customers can damage the image and efficiency of the system.

8.6 Station spacing

"Good design begins with honesty, asks tough questions, comes from collaboration and from trusting your intuition."

—Freeman Thomas, designer

Station spacing will also affect the speed and capacity of a BRT system. If stations are spaced very far apart in the manner of a metro system, reaching very high-speeds and high-capacities is quite possible. Metro systems may space stations as far apart as one kilometre or more in order to reap speed and capacity advantages.

However, the disadvantage of such an approach is the additional distance customers must traverse in order to reach the station. Therefore, BRT station spacing should try to

Box 8.3: The impacts of convoys on saturation levels

In the following example, two scenarios are developed in order to compare saturation levels for similar systems with and without the use of convoys. As noted earlier, the saturation level is calculated by the following equation:

$$X = Td * F + [(PB * Tb) + (Pa * Ta)]$$

Where:

X = Saturation level
Td = Dwell time
F = Vehicle frequency
Pb = Number of boarding passengers
Tb = Average boarding time
Pa = Number of alighting passengers
Ta = Average alighting time

The following characteristics will be common to both the scenarios (scenario with convoy and scenario without convoy):

Articulated vehicles with four, 1.1 metre-wide doors
Pb = 2,000 passengers
Pa = 1,500 passengers
F = 100 vehicles per hour

1. No convoy scenario

Ta = 0.75 * 2 / (1 + 4) = 0.3 seconds/passenger
Tb = 0.5 * 2 / (1 + 4) = 0.2 seconds/passenger

Td = 10 + (18 / 4) = 14.5 seconds/vehicle

X = [14.5 * 100 + (0.3*2,000 + 0.2*1,500)] / 3,600 seconds/hour
= 0.653

2. Convoy scenario

Two vehicles in non-ordered convoy
m = 1.33
Ta = 0.3 * 3 / (2+1.33) = 0.27 seconds/passenger
Tb = 0.2 * 3 / (2+1.33) = 0.18 seconds/passenger
Td = (10 / 1.33) + (18 / 4) = 12.2 seconds/vehicle
X = [12.2 * 100 + (0.27 * 2,000 + 0.18 * 1,500)] / 3,600 seconds/hour
= 0.566

Thus, from this theoretical example, convoying holds the potential to reduce saturation from 0.653 to 0.566, which represents a reduction of 13 percent.

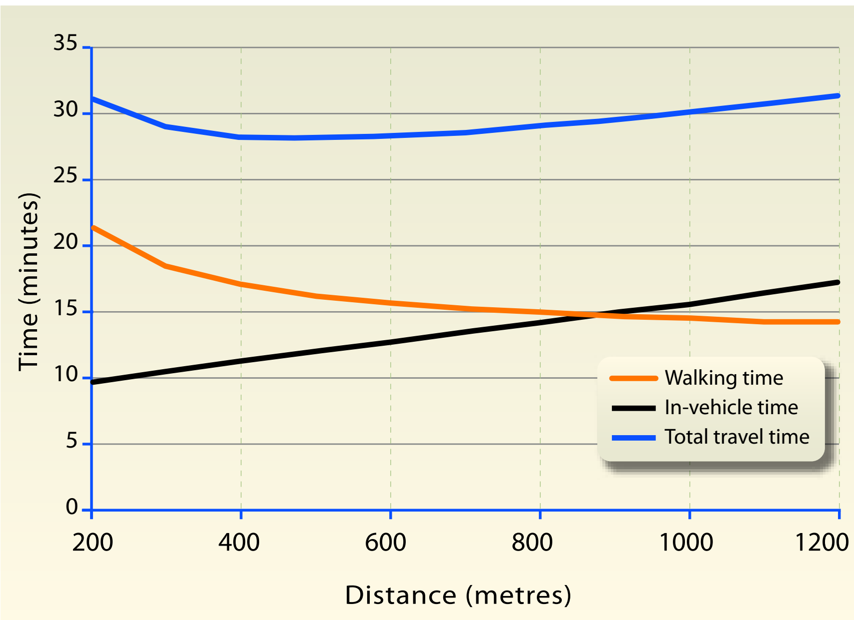
strike an optimal balance between convenience for walking trips to popular destinations, and convenience for passengers in the form of higher speed and capacity. This balance can also be better achieved if the system allows for local and limited stop services.

Locating BRT stations close to popular destinations is the best way to minimise walking times. Thus, BRT stations are typically located near major destinations such as commercial centres, large office or residential buildings, educational institutions, major junctions, or any concentration of trip origins and destinations. Usually this siting is done based on intuitive local knowledge, because traffic modelling is rarely detailed enough to provide much insight.

The spatial and right-of-way characteristics of an area will also play a role in station location. The station area will typically consume more right of way than other sectors of the BRT system.

Because BRT systems are in essence trying to provide a high-speed service that competes with metro services, designers will tend to space stations farther apart than normal bus stops. However, the distances should also represent the noted balance between walking times and vehicle speeds. In general, distances of approximately 500 meters between stations tend to be the current standard for BRT corridors. However, the actual spacing can range from 300 and 1,000 metres, depending on the local circumstances.

Fig. 8.44
Optimising total travel time as function as station separation



The optimal distance is not a constant but will vary depending on the number of boarding and alighting passengers, and the quality of the walking environment. Where there are large volumes of boarding and alighting passengers, more frequent stops will be optimal, because more people will be affected by the long walking times than will benefit from the faster vehicle speeds. In areas with very few boarding and alighting passengers, greater distances between stops will be optimal, because fewer people will benefit from the shorter walking distances, and more will benefit from the faster vehicle speeds. Figure 8.44 visually summarises the trade-off between walking times and BRT travel times in relation to the distance between stations.

In the case of Figure 8.44, the optimum point is where the total travel time (blue line) is minimised. From the figure, this point appears to occur in the range of a station separation of 400 metres to 500 metres. Box 8.4 provides a methodology for mathematically determining the optimum distance between stations.

Box 8.4: Calculating the optimum distance between stations

Optimising the distances between stops is done by minimising the generalised cost of travel for the walking distances to the stations and the travel speed of the passengers passing along the corridor.

For purposes of this example, it will be assumed that passengers walk a maximum of one-half of the distance between stations (D), and on average each passenger will walk one-quarter of this distance. Thus, walking time for boarding and alighting passengers is proportional to station distance. On the other hand, passengers in vehicles incur an additional delay for each stop, so the delay is inversely proportional to D. The calculation for determining the optimum distance between stations is as follows:

$$\mathbf{Dopt_x = [g1 * (C_x + g2 * Cmax\ ) \ /\ Pk_x\ ]^{\ 0.5}}$$

Where:

$Dopt_x$ = Optimum distance between stops in a particular area x
C_x = Peak hour bi-directional demand (crossing volume/hour) on point x
Cmax = Peak hour uni-directional maximum demand of lines that stop on stations x
Pk_x = Bi-directional density of passengers boarding and alighting near point x
g2 = A constant that reflects travel cost constants divided by walking cost constants
g1 = 4 * (Cst / Csw) * Vw * Tob
Cst = the value of walking time (US$ / walking time)
Csw = the value of time for transit passengers (US$ / transit system time)
Vw = walking speed (km hour)
Tob = Dwell time lost at each station (excluding boarding and alighting time)

For this example, the following assumptions are made:

Cst / Csw = 0.5 (*i.e.,* people value transit time twice as much as walking time)
Vw = 4 kph
Tob = 30 seconds = 1/120 hours
G2 = 0.4
C_x = 7,000 passengers per hour
Cmax = 9,000 passengers per hour
Pk_x = 2,500 passengers / kph

Based on these assumptions:

g1 = 4*0.5*4/120 = 0.067 km

$Dopt_x$ = [0.067 * (7,000 + 0.4 * 9,000) / 2,500] $^{0.5}$
= 0.533 km = 533 metres

Thus, the optimum distance between the stations in area x is 533 metres. This example assumed that passengers will value time on the transit vehicle more than walking time. This preference is not always the case, especially in areas with a high-quality walking environment.

9. Intersections and signal control

"Every doorway, every intersection has a story."
—Katherine Dunn, novelist, 1945–

Intersections represent a critical point along any BRT corridor (Figure 9.1). A poorly designed intersection or a poorly timed signal phase can substantially reduce system capacity. Finding solutions to optimising intersection performance can do much to improve system efficiency. Generally, the aim of intersection design for a BRT system is to:

- Minimise delay for the BRT system;
- Improve safe and convenient access to the bus station by pedestrians;
- Minimise delay for mixed traffic.

Fig. 9.1
Intersection design affects the public transport system's efficiency, pedestrian safety and access, and flows of mixed traffic vehicles.
Photo by Lloyd Wright

There are normally design solutions which optimise the total time savings for all modes, and achieve a reasonable balance between each of these aims. However, planners and political decision-makers will often give the highest priority to public transport vehicles and pedestrians for reasons of speed, safety and convenience.

The optimal solution depends on relative numbers of boarding and alighting public transport passengers, turning vehicles, and the bus operations. Since these factors will vary along any given corridor, it is generally not advisable to use a standard intersection configuration throughout a BRT corridor. Rather, it is best to design the intersection for the specific conditions at the given location. Intersection design is an iterative process, and the impact of a planned BRT system on overall intersection performance is often a significant consideration when deciding on the route structure of the BRT system, the location of the stations, and the design of the stations.

In BRT systems with very low vehicle volumes, relatively few passengers, and a large number of intersections, as is fairly typical in developed countries, the traffic signal may be the most significant cause of system delay. In developed countries, BRT system designers frequently focus considerable attention on reducing signal delay, and rely on a variety of traffic signal priority measures.

In developing countries, where typically the number of passengers and the number of buses per hour is much higher, where intersections tend to be fewer, and where traffic signal maintenance is less reliable, BRT system designers tend to rely more heavily on turning restrictions to improve intersection performance. In either case, improving the efficiency of the intersections is important.

BRT systems with physically segregated lanes create new turning conflicts. Whereas buses in mixed traffic can move to a mixed traffic left turn lane when turning left, and to a right turn lane when turning right, in a physically separated busway the buses are physically constrained from moving to the other side of the road. If designed poorly, the introduction of BRT can lead to a multiplication of signal phases at the intersection, and/or a multiplication of turning lanes, delaying both the busway and the mixed traffic and consuming right of way at the intersection that might be better used for pedestrian facilities or other alternative uses, or requiring costly land acquisition. To avoid these problems, BRT system planners have tended to approach intersections in the following manner:

1. Identify existing bottlenecks and resolve using standard engineering practice;
2. Simplify the BRT system's routing structure;
3. Calculate the projected traffic signal delay on the new BRT system;
4. Restrict as many mixed traffic turning movements on the BRT corridors as possible;
5. Decide on an approach to turning movements within the BRT system;
6. Optimise the location of the station;
7. Optimise the intersection design and the signal phasing;
8. In low volume systems, consider signal priority for public transport vehicles;
9. In high-volume systems, consider grade separation of busway at intersections (*e.g.,* an underpass).

The following sections provide some general rules for making reasonable design decisions in these cases. The topics discussed in this chapter are:

9.1 Evaluating the intersection

"True genius resides in the capacity for evaluation of uncertain, hazardous, and conflicting information."

—Winston Churchill, former British Prime Minister, 1874–1965

9.1.1 Intersection audits

BRT systems are generally built on corridors where mixed traffic congestion is already a problem, or where congestion is likely to occur in the near future, otherwise there would be no benefit of building a segregated busway. The worse the congestion appears, the greater the benefit of the exclusive busway (Figure 9.2). If a BRT system makes public transport services better but mixed traffic worse, it will be less politically successful than if it makes public transport better and also improves mixed traffic flow. BRT system planners therefore generally try to minimise adverse impacts on mixed traffic.

In developed countries, traffic departments have frequently spent large sums of investment in optimising intersections. In developing countries, by contrast, existing intersection design is frequently sub-optimal from the point of view of vehicular throughput and speed. This situation increases the chances that a new BRT system can be designed in a way that actually improves both public transport performance and mixed traffic flow. In short, general intersection improvement measures along the BRT corridor can usually be identified that will offset any new intersection inefficiency resulting from the implementation of the new BRT system.

As a first step, therefore, BRT system planners should carefully review the existing mixed traffic bottlenecks in the corridor. It is frequently the case that a small number of bottlenecks are responsible for the vast majority of mixed traffic delay. These bottlenecks are usually due to one or more of the following conditions:

Fig. 9.2
The introduction of BRT and design changes to poorly controlled and congested intersections often leads to efficiency improvements for both public transport vehicles and mixed traffic.
Photo by Lloyd Wright

- Badly placed bus stops or unregulated stopping of public transport vehicles;
- Narrow bridges and tunnels;
- Lack of grade separated railway crossings;
- Traffic convergence points;
- Poorly regulated parking;
- Sub-optimal timing at traffic signals;
- Improperly designed and channelised intersections.

For example, on the TransJakarta Corridor I, the vast majority of congestion was caused by only four problem locations, three of which were intersections, and the other was at a commercial centre with problems of parking, double parking, and exiting and entering vehicles. Figure 9.3 illustrates the vehicular saturation along a planned BRT corridor. In this case, vehicle saturation (the variable "x") is measured as vehicle volume divided road capacity.

From the example given in Figure 9.3, the most serious bottlenecks (*i.e.,* points A , B, and E) are signalised intersections. The capacity of the intersection is generally a function of the amount of green time per lane. The amount of green time per lane is generally a function of the number of signal phases. Saturation can increase up to 300 percent by increasing an intersection from two or three phases to four phases. Point C might be a bridge or tunnel where, for example, lanes are reduced from 3 to 2, increasing saturation by 50 percent. Point D might be a popular destination like a shopping mall where an extra volume of vehicles enters the road, increasing saturation. It might also be a popular bus interchange, a street market, or an area with regulated on-street parking area.

Quite often a new BRT system can lead to a reduction of the number of lanes available to mixed traffic. While ideally the removal of a large number of buses from the mixed traffic lanes will avoid worsening congestion in the mixed traffic lanes, this is not always possible, and mixed traffic saturation may increase (from the blue to the red line in Figure 9.3). Congestion, before restricted to point B, now occurs at A, B, C and E. Due to the implementation of

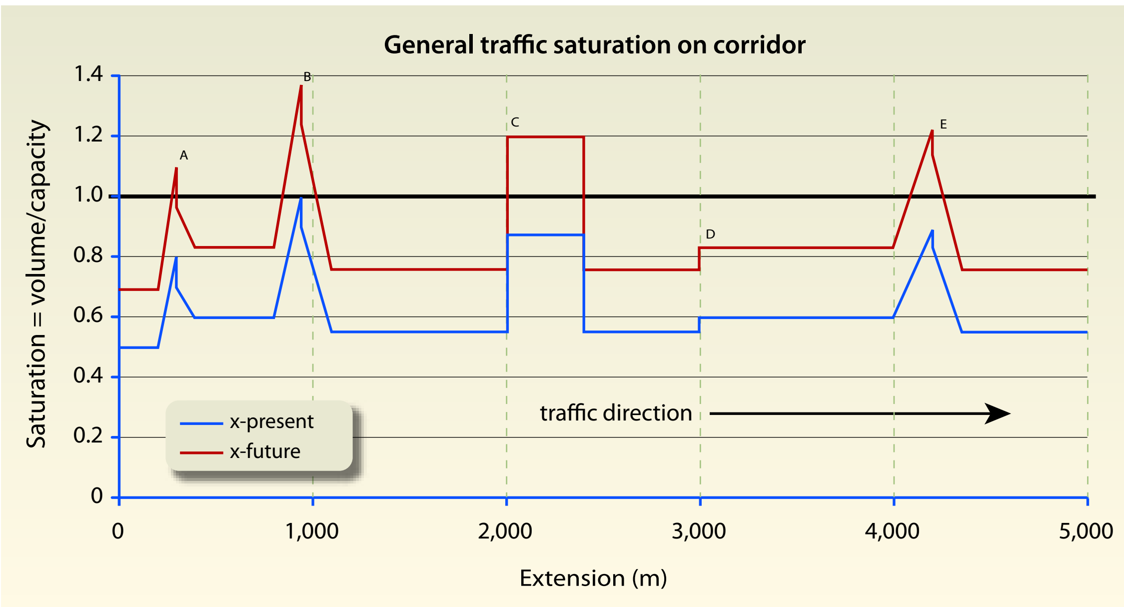


Fig. 9.3
Mixed traffic saturation along a BRT corridor.

the BRT project, these points now require more careful attention than before.

The non-intersection bottlenecks should be addressed first. These problem points can generally be resolved through a combination of tightening parking regulation and enforcement, tightening vendor regulation and enforcement, narrowing medians, improving parallel roads, or widening roads if all else fails.

Generally, the easiest and least expensive solution is to improve the efficiency of the intersections. While simply redesigning these intersections without the BRT system would have significantly improved traffic flow, packaging these intersection improvements with the introduction of the new BRT system will not only help to improve the public acceptance of the new BRT system. The implementation of the new BRT system requires changing the intersection design anyway, so the opportunity should be taken to improve the overall efficiency of the intersection. The less efficient the intersection was before the BRT system, the easier it will be to design the new system in a way that improves conditions for both public transport passengers and mixed traffic.

9.1.2 Calculating the impacts of signal delay

"All change is not growth, as all movement is not forward."

—Ellen Glasgow, novelist, 1874–1945

Once the basic routing structure of the new BRT system has been determined, system designers should have a reasonable idea about likely vehicle frequencies within the BRT system. The first analysis should then be to determine if the busway will congest given the current intersection signal phasing and lane allocation along the BRT corridor. Each intersection in the corridor should be analysed.

To optimise any given traffic signal in the BRT corridor, priority should be given to reducing saturation for the public transport vehicles. This optimisation is much less complex than avoiding saturation at the stations, and will largely be a function of the cycle time and the vehicle frequency.

The total traffic signal delay in a busway is a function of two separate phenomena. First, the traffic signal delay is a function of simple delay, which is caused by too many vehicles using the busway relative to the intersection's capacity. Second, delays may be caused by the random occurrence of buses queuing. Equation 9.1 outlines the calculation of total traffic signal delay based on these two factors.

If the system planners have already given priority to buses along a particular corridor, and the signal phases have been simplified to as few as possible by restricting turns, then the BRT vehicles should benefit from much green phase time. Once this optimisation is done, the capacity of the intersection in terms of buses per hour will be very high, probably more than 200 buses per hour, which is more capacity than most busways will actually need.

Equation 9.1 Calculation of total signal delay

$$TS = TF + TQs$$

Where:

TF = Average signal delay per bus (the average amount of time it takes a bus to pass through the intersection)

TQs = Queuing delay (The random queue that forms at signals resulting from the fact that buses do not generally all arrive evenly dispersed, but rather in bunches.

The average delay (TF) is a function of the red time and the level of congestion within the busway (Equation 9.2).

Equation 9.2 Calculation of average delay

$$TF = TR^2 / (2*TC*(1-F/S)$$

Where:

TF = Average delay
TR = Time the traffic signal is red
TC = Total cycle time
F = Bus frequency per hour
S = Saturation flow, in bus units per lane, on the approach to the intersection.

The term "S" is a constant that is defined based on the type of bus. Assuming that there are no station stops, the intersection for a bus lane will be able to handle just a few less buses than it would be able to handle private cars, based on the passenger car units attributed to the specific bus.

In the example below, the intersection has been designed to heavily prioritise the BRT corridor, approximately 40 seconds of red time and 40 seconds of green time have been attributed to the BRT system (the actual red and green time will be reduced by the amount of yellow time). With this signal phasing, for articulated 18.5-metre buses, "S" will be roughly equal to 720, and for 12-metre buses, "S" will be approximately 900, or slightly less than what the intersection could handle if they were private cars.

Example:

TC = 80 (80 seconds in the signal cycle)
TR = 40 (40 seconds of red time)
F = 200 (200 articulated buses/hour)
S = 720 (intersection capacity for articulated buses for one lane/hour)

In this case, the intersection would be able to handle 200 articulated buses per hour per lane, which is far more than a typical BRT system would require. A standard BRT busway lane would move nearly 10,000 passengers per hour per direction with just 60 articulated buses per hour per lane.

In the example given, the average intersection delay would be:

$TF = 40^2/(2*80*(1-200/720)) = 13.8$ sec

Thus, if there are 200 articulated buses per hour in a single lane and there is an 80 second traffic signal cycle with up to a red phase of 35 seconds, there is no difference between total signal delay and average signal delay. In this case there is no additional delay resulting from bus queues at the stop light. However, if there is more than 35 seconds of red time, the random queuing of buses at the traffic light begins to add additional delay.

The random queuing delay (TQs) is a function of the saturation of the signal in the bus lane (Xs), vehicle saturation (x), and the intersection capacity (S).

Equation 9.3 Calculating the random queuing delay

$$TQs = [(Xs-x) / (1-Xs)] / S$$

Where:

Xs = Saturation of the signal in the bus lane
x = Vehicle saturation
S = Saturation flow, in bus units per lane, on the approach to the intersection.

Equation 9.4 provides the calculation of the term "Xs".

Equation 9.4 Calculating the saturation of the signal in the bus lane

$$Xs = (F / S) / (1-TR/TC)$$

Based upon the previous example:

$Xs = (200/720) / (1-40/80) = 0.5555$

The value of the vehicle saturation level will be quite determinant on the extent of any possible queuing delay. There are essentially three distinct possibilities:

a. If $x<0.5$, then TQS equals 0, and there is no queuing delay
b. If $0.5<x<1$, then the degree of queuing delay is determined as: $TQs = [(x-0.5)/(1-x)] / F$
c. If $x >1$, then there will be severe busway congestion.

Based upon the previous example and a saturation value of 0.5 ($x=0.5$), TQs is

Table 9.1: Total signal delay and saturation as a function of red light cycle duration

Red light cycle duration (seconds)	Average signal delay (TF) (seconds)	Random queuing delay (TQs) (seconds)	Total signal delay (TS) (seconds)	Saturation level (x)
0	0.00	0.00	0.00	0.28
10	0.87	0.00	0.87	0.32
20	3.46	0.00	3.46	0.37
30	7.79	0.00	7.79	0.44
36	11.22	0.18	11.40	0.51
40	13.85	2.25	16.10	0.56
42	15.27	3.68	18.94	0.58
43	16.00	4.53	20.53	0.60
44	16.75	5.52	22.27	0.62
45	17.52	6.65	24.18	0.63
46	18.31	7.98	26.29	0.65
47	19.12	9.56	28.67	0.67
48	19.94	11.45	31.39	0.69
49	20.78	13.78	34.56	0.72
50	21.63	16.71	38.35	0.74
51	22.51	20.51	43.02	0.77
52	23.40	25.62	49.02	0.79
53	24.31	32.86	57.17	0.82
54	25.23	43.94	69.18	0.85
55	26.18	63.00	89.18	0.89
56	27.14	103.50	130.64	0.93
57	28.12	248.14	276.26	0.97

TQs = [(0.5555-0.5) / (1-0.55555)] / 200
= 0.0006244 hours
= 0.0006244 hours *3600 seconds/hour
= 2.25 seconds

Thus, based on these values of average signal delay and queuing delay, the total delay experienced for each bus is:

TS = TF + TQs
= 13.8 seconds + 2.2 seconds
= 16 seconds

Table 9.1 provides sample values of signal delay for different red light durations. The values are based on the sample conditions of a single busway lane per direction, a total signal phase cycle of 80 seconds, and a busway flow of 200 articulated vehicles per hour.

In summary, intersection delay is largely a function of red time as a share of total signal time. If saturation is greater than 0.65, random delay becomes significant, and the project design should be changed to give a higher proportion of green time, and/or a second BRT lane on the approach to the intersection should be considered.

9.2 Restricting turning movements

"Change means movement. Movement means friction. Only in the frictionless vacuum of a nonexistent abstract world can movement or change occur without that abrasive friction of conflict."

—Saul Alinsky, activist, 1909–1972

Optimising a BRT system to handle the highest number of passengers is often at odds with optimising the system to move at the fastest operating speeds. From the point of view of passenger demand, it is best to have a lot of routes feeding into the BRT system, and for the BRT system to have a dense network of interconnected routes. Turning movements can be quite positive in terms of allowing different routes to intersect. These types of interconnections will also tend allow customers to transfer between routes at platforms rather than walking long distances across intersections.

However, each time a turning movement is introduced into the BRT system, it introduces some additional delay either by complicating the intersection or by forcing buses to leave the busway. For this reason, it is generally a good idea to take another look at the routing structure of the planned new BRT operations from the perspective of whether or not the routing structure can be simplified. A balance should be struck between the density of the BRT network and the impact that turning movements have on average speeds.

Fig. 9.4
Prior to Quito's Ecovía line, mixed traffic vehicles were allowed to cross through this intersection as well as negotiate right and left turns. To give priority to public transport, straight and left turn movements have been blocked.
Photo by Lloyd Wright

In many projects to date, a standard technique for increasing BRT travel speeds and reducing signal delay is to restrict as many mixed traffic turning movements across the corridor as possible (Figure 9.4). If the busway is reaching saturation, or the introduction of the BRT system increases mixed traffic saturation to critical levels, it becomes imperative to consider some form of turning restrictions.

9.2.1 Techniques for reducing the number of signal phases

"On a traffic light green means go and yellow means yield, but on a banana it's just the opposite. Green means hold on, yellow means go ahead, and red means where the hell did you get that banana."

—Mitch Hedberg, comedian, 1968–2005

In ideal circumstances, the movements of BRT vehicles are unencumbered when passing an intersection. However, unless a system can be fully grade separated at an intersection (*i.e.*, through an underpass or overpass), some conflicts are likely to occur with mixed traffic movements.

Table 8.9 shows how different methods of simplifying the signal phase will impact the

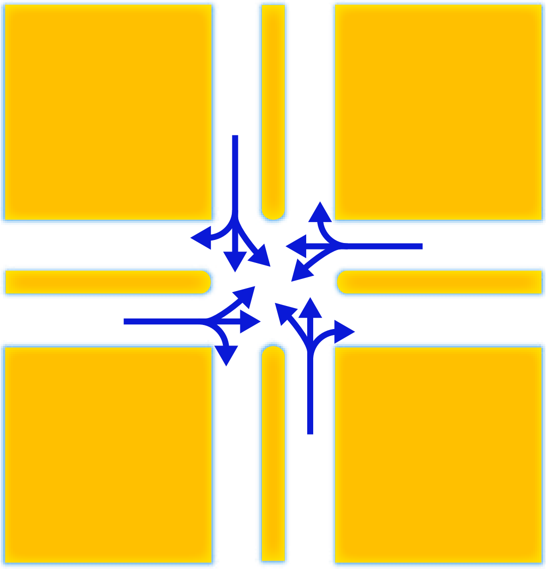


Fig. 9.5
Representation of possible turning movements at a typical intersection.

overall capacity of an intersection, assuming all other aspects are equal. The values given in Table 8.9 are just reference values for a unique set of conditions. The actual values in any given intersection will vary according to volume distribution and local geometry.

Figure 9.5 represents the starting point of evaluating a standard intersection, as projected by the calculations in Table 9.2. This figure outlines each of the possible turning movements. A standard assumption may be to project that left and right turns each represent 25 percent of the mixed traffic movements, and continuing straight represents 50 percent of the mixed traffic movements. For simplicity purposes, all approaches are identical in terms of vehicle volumes. In evaluating an actual intersection, the planning team would conduct peak and non-peak counts of all vehicle movements.

Table 9.2: Intersection capacity for different turning configurations

Option	Phases	Location of cross turning movement (left turn)	Location of side turning movement (right turn)	Capacity at intersection (passenger car units per lane per hour)
At-grade options				
A	4	Allowed at intersection	Allowed at intersection	450
B	4	Allowed at intersection	Allowed at intersection	600
C	2	U-turn after intersection and then a right turn	Allowed at intersection	760
D	2	Three right turns after intersection	A combination of right-left-right prior to intersection	950
E	2	A combination of right-left-left prior to intersection	A combination of right-left-right prior to intersection	1,267
F	2	A combination of left-right-left prior to intersection	Allowed at intersection	1,267
G	2	A combination of left-right-left prior to intersection	A combination of right-left-right prior to intersection	1,900
Grade-separated options (*i.e.,* use of flyover or underpass)				
H	4 + underpass	Allowed at intersection	Allowed at intersection	700
I	3 + underpass	Allowed at intersection	Allowed at intersection	800
J	Underpass	Three right turns after intersection	Allowed at intersection	1,600
K	Underpass	Three right turns after intersection or a combination of right-left-left prior to intersection	A combination of right-left-right prior to intersection	2,000

9.2.1.1 At-grade options

From table 9.2, scenarios "A" and "B" are standard four-phase intersections, and the capacity of the intersection per lane is very low. In scenario "A", left turn movements are given their own signal phase, with two directions being able to left simultaneously (Figure 9.6).

As an alternative, the configuration for option "B" is four phases with just a single directional approach on each phase (Figure 9.7).

For both options "A" and "B", each approach faces a green signal less than one-quarter of the time since there is also some time devoted to yellow signal phases. Usually the average vehicle capacity per lane per hour is just 450 passenger car units (pcu) per lane per hour. By comparison vehicle capacity for expressway conditions is 2000 pcu/lane/hour.

If a one-way BRT system with no turns is introduced into the median of an intersection with standard four-phase signal phasing, option "A" is likely to be preferred. Option "B" will lead to conflicts between buses going straight and vehicles turning left. This conflict could be potentially overcome with an additional signal phase, but this additional phase would reduce BRT green phase length even further. In using option "A", BRT buses are provided with at most one-quarter of the total time as a green phase (Figures 9.8 and 9.9).

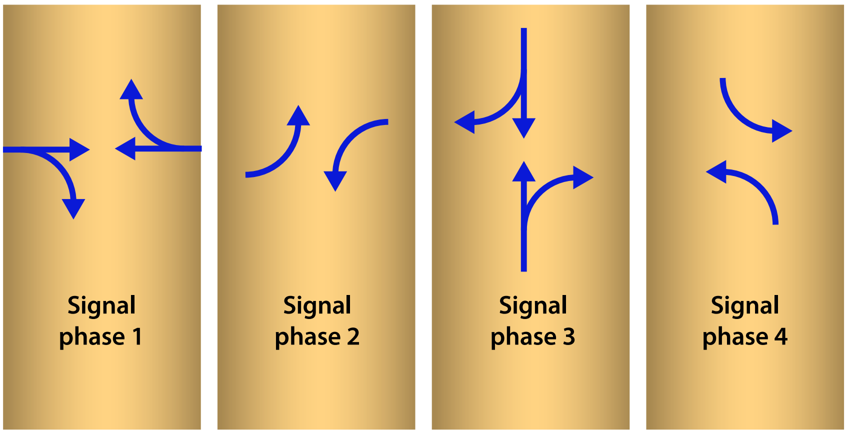


Fig. 9.6
Option "A"

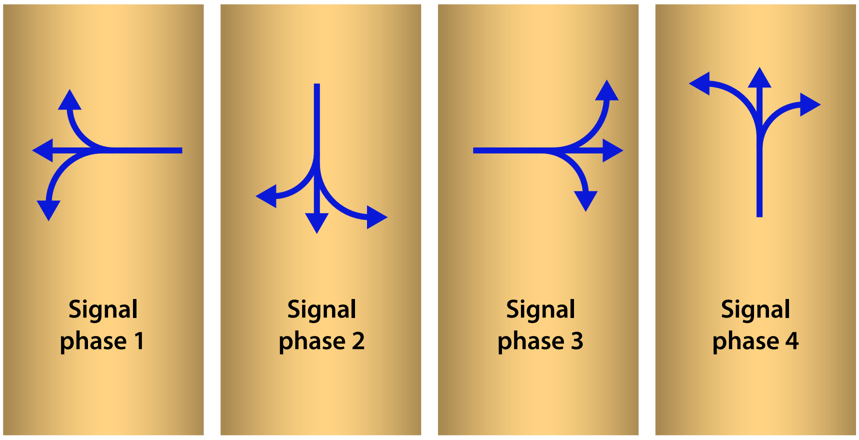


Fig. 9.7
Option "B"

Fig. 9.8
Along Quito's Central Norte corridor, mixed traffic vehicles are given a phase to perform left turns.
Photo by Lloyd Wright

Fig. 9.9
The green phase for a BRT vehicle entering the Val de Marne busway in Paris.
Photo courtesy of the National Bus Rapid Transit Institute (NBRTI)

each direction. This additional lane gives mixed traffic vehicles a dedicated lane for left turns (or right turns for British-style road systems). By creating left turning lanes in both directions, the delays caused by waiting left turning vehicles can be reduced, and the capacity of the intersection per lane can increase up to 600 pcu/lane/hour.

To make this modification, space must be available at the intersection to provide a left turn lane for mixed traffic. This is generally more easily done if the BRT station is not located immediately adjacent to the intersection. However, locating the station farther from the intersection may cause inconvenience for passengers that need to transfer to perpendicular roads. Thus, some analysis of the time savings benefit of pedestrians relative to turning motorists may be required.

For options "C" through "G", left turns are eliminated. The traffic signal is reduced to only two phases, and left turning traffic has to find some other place to make a left turn. This phase configuration thus removes the need for the mixed traffic turning lane at the intersection, which allows the BRT station to be moved to the intersection if desired.

Figure 9.10 illustrates the standard two phase traffic signal phase when left turns are disallowed.

By doubling the green time given to the BRT vehicles, the capacity and speed of the busway and mixed traffic is increased significantly for a very limited cost. For each alternative, the average lane capacity will vary depending on how the left turning traffic was accommodated.

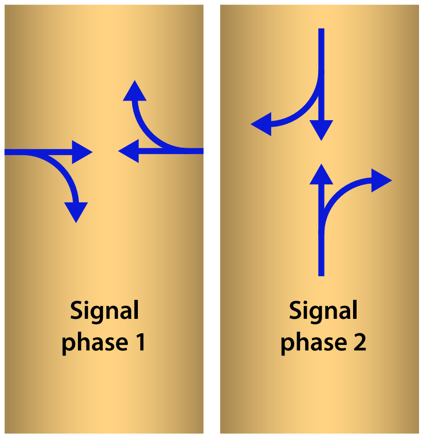


Fig. 9.10
Signal phases for options "C" through "G" (i.e., scenarios in which left turns are disallowed).

In option "C", there are no alternative routes for left turning vehicles, so the elimination of left turns on one road requires the creation of two opposite u-turns on the BRT corridor itself (Figure 9.11).

In option "C", as all left turn movements have to pass through intersection twice, the capacity of the intersection increases just to 760 pcu/lane/hour. Further, the act of making a u-turn along the busway can create conflicts for the BRT system.

In option "D", the vehicle turns left by either making three right turns, or by making a right

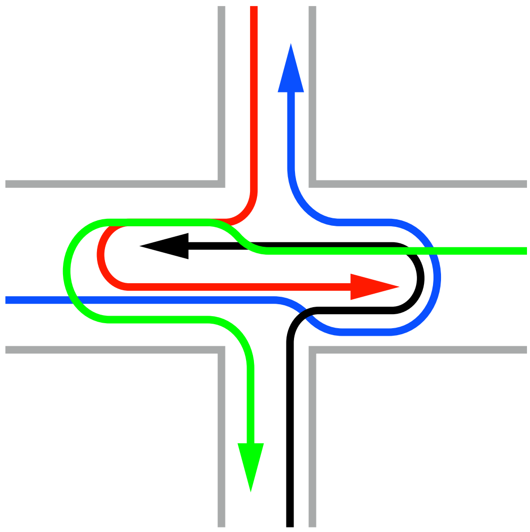


Fig. 9.11
In option "C", a left turn for mixed traffic vehicles is accomplished through a u-turn along the busway.

turn and two subsequent left turns (Figure 9.12). Right turning traffic is forced to turn at a previous intersection, and make a turning combination of right – left – right. This measure still requires left turning vehicles to pass through the intersection twice, but removes right turning vehicles from the intersection all together. This measure can increase capacity to 950 pcu/lane/hour.

Unfortunately, the lack of a dense secondary street network can render option “D” through “G” ineffective. Without a set of nearby adjacent streets for turning, mixed traffic vehicles could be forced into extremely long detours.

Option “E” is similar to option “D”, but instead for the left turning movement, a right turn is initiated prior to the intersection (Figure 9.13). This configuration thus entails a turning combination of right-left-left in order to complete the full left turn. In this case, left movements pass through the main intersection only once. An additional signal may be needed to cross the main corridor, but the capacity increases to 1,267 pcu/lane/hour.

Like option “E”, option “F” also involves a turn prior to the intersection. However, in this case, the sequence is begun with a left turn. The full combination for scenario “F” is thus left-right-left (Figure 9.14). This scenario implies the need for two additional traffic signals. If the right turn in this case is made at the intersection, the intersection capacity will be 1,267 pcu/lane/hour.

Option “G” is the same as option “F”, but in this case, the right turn is also made before the intersection (Figure 9.15). The capacity under option “G” increases significantly to 1,967 pcu/lane/hour. To implement this option eight or more additional traffic signals (two for each approach) could be required.

Options “F” and “G” require an even greater density of auxiliary roads which is often simply not available.

Real-world scenarios cases usually use a combination of all these possible options. Optimising the selection of which measures are appropriate in each case can be a matter of both calculus and art. However, capacity increases with these types of solutions generally compare highly

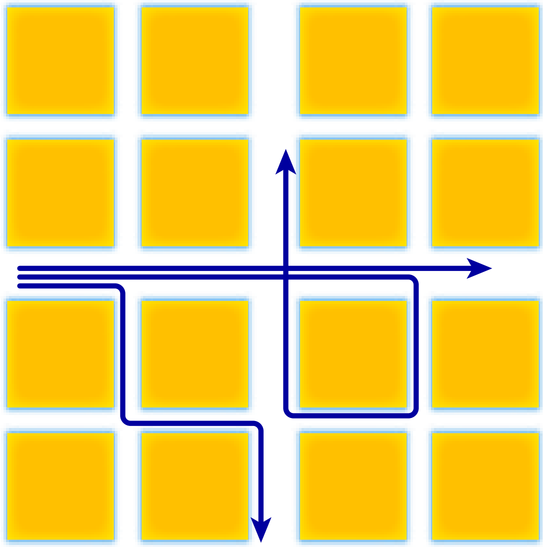


Fig. 9.12
Option “D”

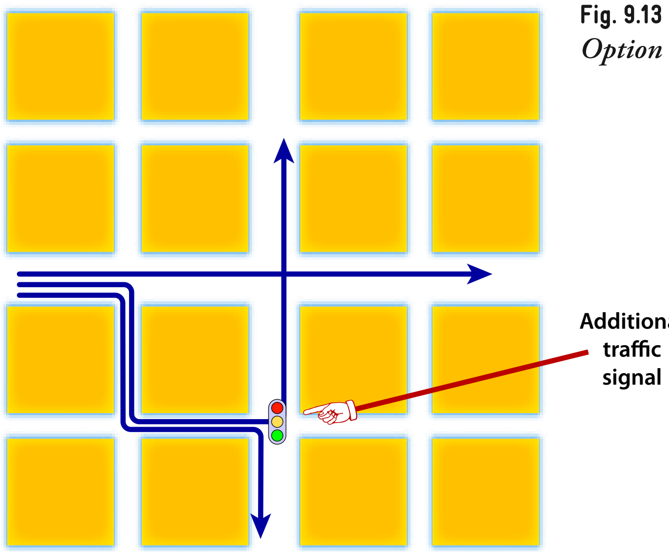


Fig. 9.13
Option “E”

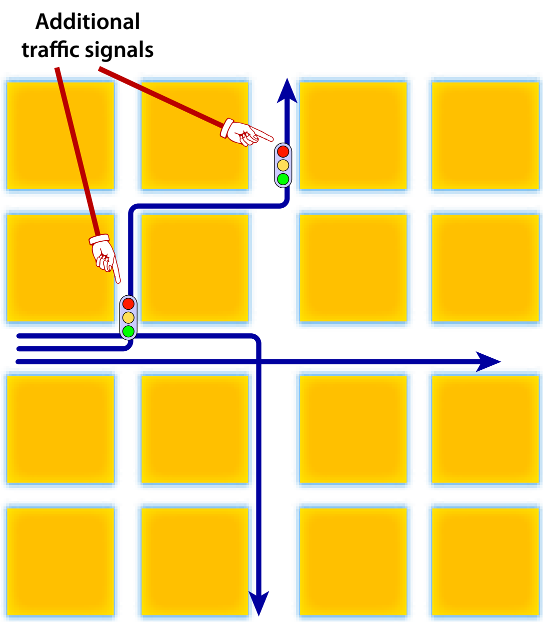
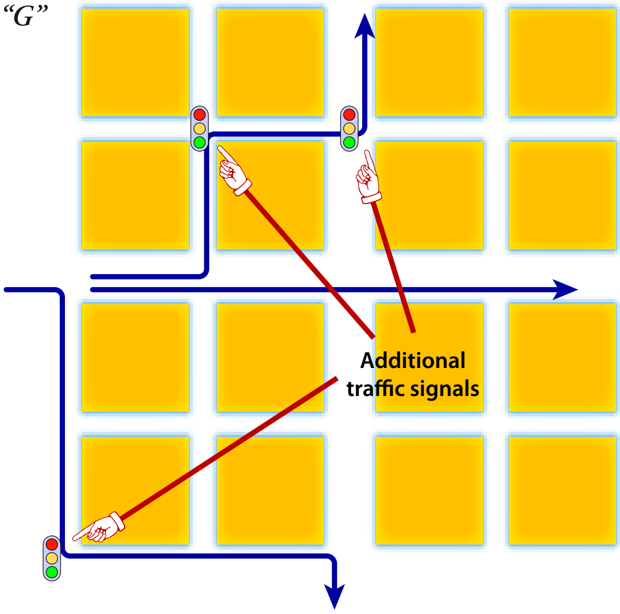


Fig. 9.14
Option “F”

Fig. 9.15 *Option "G"*



favourably with relatively inefficient results achieved from using four-phase traffic signals.

9.2.1.2 Grade-separated options

Typically, when the capacity of a 4-phase intersection is reaching saturation (more than 600 vehicles/lane/hour), it is fairly typical for engineers to suggest the construction a flyover or an underpass that allows straight movement for one main road (2 of the 12 movements), while all other movements remain at the same level. The introduction of flyovers or underpasses can cause specific difficulties for BRT systems. At the same time, the flyover or underpass represents an opportunity to dramatically improve BRT vehicle movements through the intersection. Exclusive busway use of a flyover or underpass is a highly successful technique used in several existing BRT systems. Thus, a first option is to consider grade separation infrastructure that is dedicated to BRT usage.

A second possibility is when the flyover is built on the road perpendicular to the BRT corridor. In this case, the flyover does not introduce any special difficulty and can help to decongest a BRT intersection and increase green phase time.

If a single flyover in the median is built for mixed traffic while BRT buses are forced to use surface streets, the buses in the median must cross the mixed traffic going over the flyover. This problem is being confronted in Delhi. This scenario creates either the need for a new signalised intersection prior to the flyover, or it requires a merge lane where the BRT buses and mixed traffic can cross, introducing possible delay and confusion for both the BRT system and the mixed traffic. Figure 9.16 shows the conflict in a planned BRT system in Delhi where it must cross a mixed-traffic only flyover. Clearly, in this scenario, it would be far better to dedicate the flyover (or at least the middle lanes of the flyover) to the BRT system.

A third possibility is to construct two separate flyovers, one for traffic in each direction, leaving a space between the flyover for the BRT system that allows BRT buses to continue along the surface. A fourth possibility is to allow the BRT vehicles to also pass over the flyover, either in a segregated lane, or if there is no space for a segregated lane, then in mixed traffic. This last option sometimes results in stations being far from intersections, which may produce inconvenience for passengers seeking to reach destinations near the intersection. Additionally, this configuration can be particularly problematic if there is a connecting BRT corridor running on the perpendicular street below the flyover or above the underpass.

Option "H" shows the limited benefit of using a flyover or underpass if the BRT lanes remain at the surface level and four-phase signal timing is

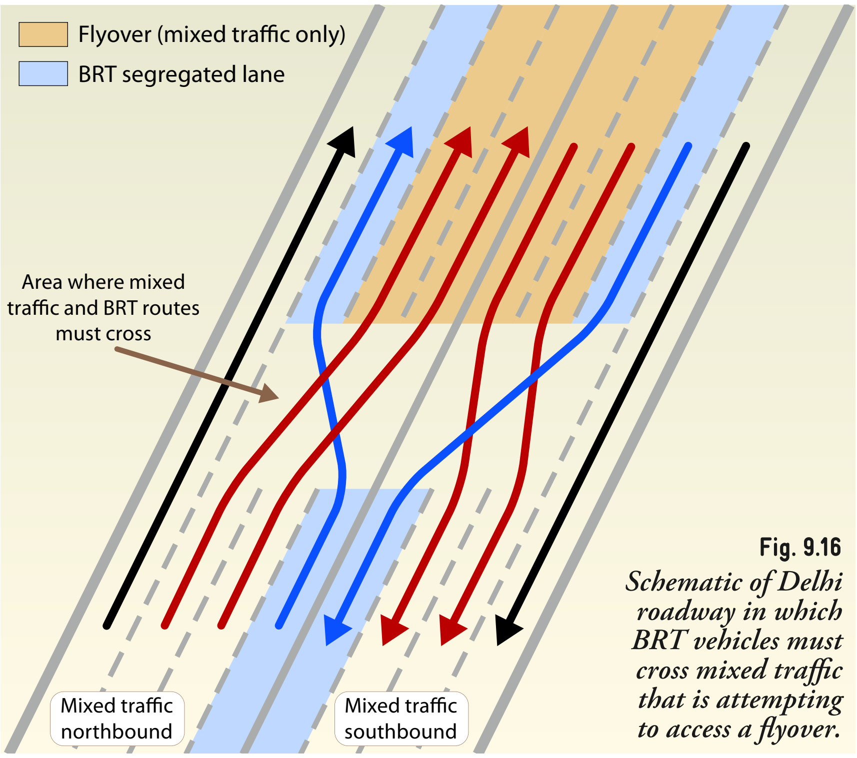


Fig. 9.16
Schematic of Delhi roadway in which BRT vehicles must cross mixed traffic that is attempting to access a flyover.

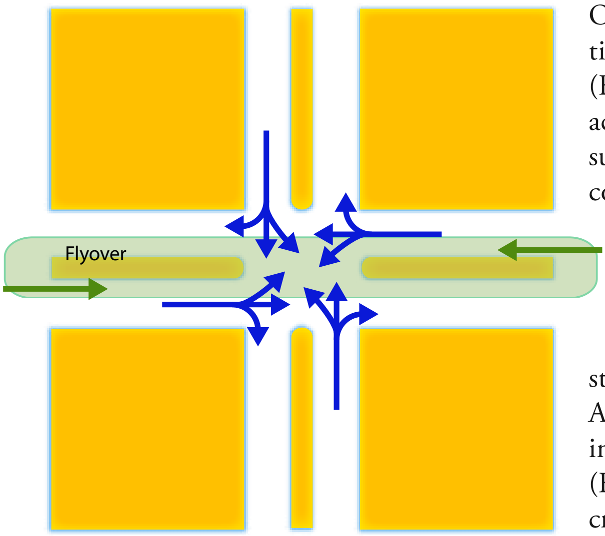


Fig. 9.17
Option "H"

Option "H" is fairly common with conventional bus services in cities such as Bangkok (Figure 9.18). Mixed traffic vehicles have access to the flyover and thus are given a substantial priority at the intersection. By contrast, public transport vehicles servicing the intersection area are often mired in heavy congestion.

Option "I" is typical along a proposed BRT corridor in Guangzhou. In this case, all straight movement is relocated to the flyover. As a result, the number of signal phases for intersection on the surface is reduced to three (Figure 9.19). For this option, capacity increases marginally to 800 pcu/lane/hour.

maintained (Figure 9.17). In this scenario, the overall increase in intersection capacity is quite small with the capacity only rising from 600 pcu/lane/hour to 700 pcu/lane/hour.

Fig. 9.18
While mixed traffic vehicles can bypass a congested intersection in Bangkok, public transport vehicles are often consigned to serving stations near the intersection. The result can be slow average speeds for public transport.
Photo by Lloyd Wright

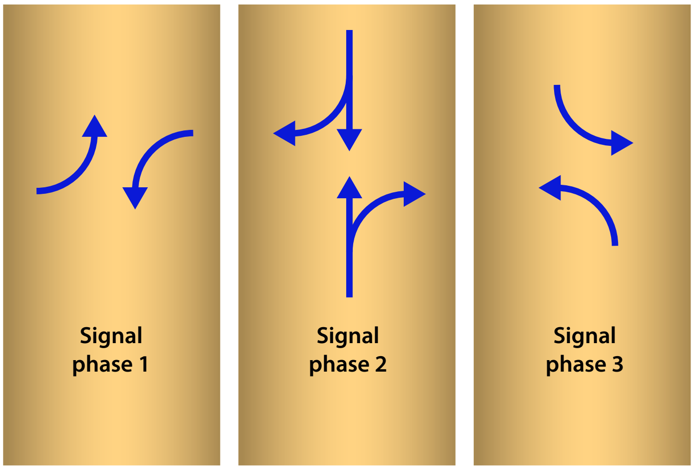


Fig. 9.19
In option "I", the presence of a flyover handling all the straight vehicle movement in one direction (both mixed traffic vehicles and BRT vehicles), reduces the number of surface level phases to three.

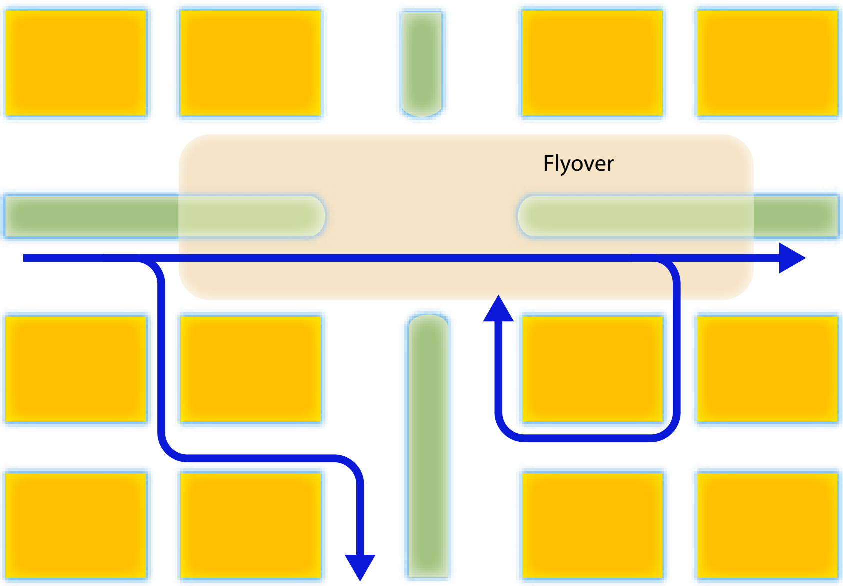


Fig. 9.20
Combining grade separation with limitations on turning movements can produce intersection capacities as high as 2,000 pcu/lane/hour.

Options "J" and "K" combine grade-separation infrastructure with limitations on turning movements. Thus, options "J" and "K" essentially replicate many of the turning movements from option "D" but with the added benefit of grade separation in some directions. In some cases, this combination may necessitate off-ramps from the flyover in order to facilitate certain turning movements (Figure 9.20). The combination of these configurations dramatically increases the intersection's potential capacity. Option "J" is capable of delivering a capacity of 1,600 pcu/lane/hour while option "K" produces a capacity of 2000 pcu/lane/hour.

While both flyover and underpass options are presented here, underpasses are frequently a preferred option from a standpoint of aesthetics. The proliferation of flyovers within a city environment can do much to scar an area's visual image. However, in cases where the road base is hard bedrock, underpass construction may be prohibitively expensive. Likewise, if an area possesses a high water table, then an underpass may not be technically viable or desirable.

This section has highlighted the idea that on any BRT corridor there are generally critical intersections where the addition of the new BRT system will create conditions nearing saturation. If full four-phase signalisation is maintained in such conditions (options "A", "B", "H", or "I"), then congestion is a likely result. The best solutions tend to involve restrictions on turning movements plus, in some cases, grade separation. Typically, turning restrictions and grade separation are far more effective in maximising intersection capacity than signal prioritisation or green-wave signal phasing.

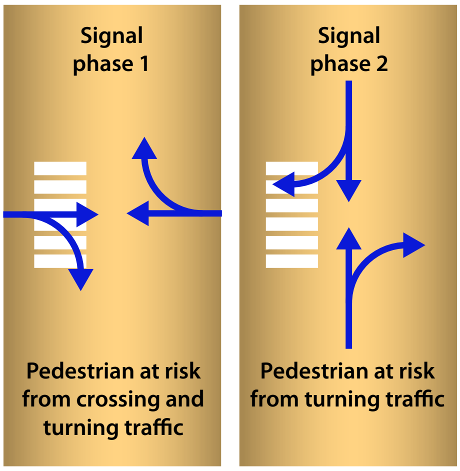


Fig. 9.21
In a standard two-phase traffic signal, pedestrians are potentially at risk during both phases.

Any intersection, though, cannot be analysed in isolation. Optimum results are usually obtained when vehicle movements are not only analysed at the particular intersection but also along the corridor and the entire extended area close to the intersection.

9.2.2 Integrating pedestrian and cyclist movements

"The way I see it, I can either cross the street, or I can keep waiting for another few years of green lights to go by."

—Camryn Manheim, actress, 1961–

A highly efficient intersection for mixed traffic and BRT vehicles may not be user-friendly to other street users, especially vulnerable users such as pedestrians and cyclists. Further, the entire viability of the BRT system can be undermined if the surrounding pedestrian environment is not amenable to attracting customers to the BRT station. This section examines design options that not only are conducive to effective vehicle movements at intersections but also options that successfully accommodate pedestrian and cyclist movements.

A standard two-phase traffic signal configuration does not offer any exclusive movements for pedestrians (Figure 9.21). The pedestrian is blocked by crossing or turning traffic in either phase. In such circumstances, the pedestrian must seek a discernible break in the traffic and make a quick crossing. Obviously, such conditions put pedestrians at considerable risk.

The lack of safe pedestrian options can also be the case for three and four phase intersections, depending on the configuration. If intersections are designed to slow turning vehicles and if turning vehicle volumes are not that high, the problem may not be serious. However, if turning volumes are high or intersections allow high speed right turns, bicyclists and pedestrians going straight will have problems crossing the road.

The normal solution to this problem is the creation of a pedestrian refuge island between the right turn slip lane and the intersection and not allowing right turns (or left turns in British-style systems) during the red signal phase (Figure 9.22). Pedestrians can generally cross to this pedestrian refuge island during the red phase, and then cross when the light turns

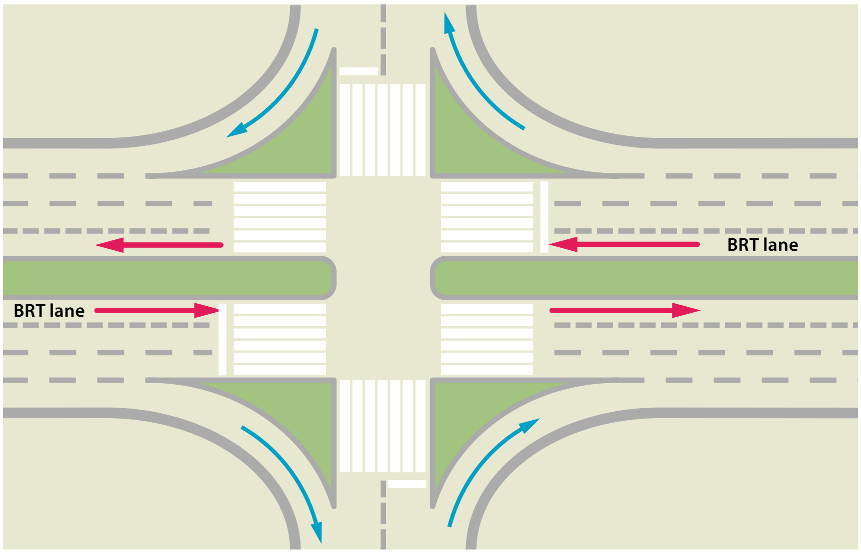


Fig. 9.22
The introduction of a pedestrian island between the right-turn lane and the crossing can significantly help pedestrians safely cross within the standard two-phase traffic signal.

green. Another possible solution for this is a short "leading pedestrian interval" that allows pedestrians to cross in front of right turning vehicles prior to the change of the signal to green. This option still requires disallowing right turns on the red signal but mitigates the need for the pedestrian refuge island. More discussion on safe pedestrian access is included in Chapter 13 (*Modal integration*).

For cyclists, intersection risks often emanate from turning vehicles that threaten straight movements by the cyclists. Since the motorised vehicles are often travelling much faster than the bicycles, there is a great potential for conflict and risk at turning locations. Cyclists may feel particularly vulnerable when wanting to turn left (or right in a British-style configuration).

There, are at least two mechanisms for permitting cyclists to safely navigate intersections:

- Infrastructure giving physical priority to cyclists and allowing them to cross prior to private vehicles; and/or,
- Dedicated signalisation for cyclists.

In several countries, dedicated areas located in front of the stopping line for motorised vehicles have been an effective option (Figures 9.23 and 9.24). The idea is to give cyclists a head start over motorised vehicles in crossing the intersection. The cyclists are given a designated box to wait for the green signal phase. In some cases, this physical priority can be combined with a dedicated signal phase as well.

A schematic of the bicycle priority measures utilised in Xi'an is given in Figures 9.25 for each of the two signal phases.

Dedicated signal phasing for bicycles is increasingly common, especially in the presence of a median cycleway. Cycleways in Bogotá and Rio de Janeiro make use of such signalisation (Figure 9.26). A dedicated green phase for bicycles gives cyclists an added sense of security.

The addition of a median busway does make for an added complication, but it is still quite possible to adequately accommodate safe cyclist movements and maintain a high-volume public transport system. One option is to place both a dedicated busway and a dedicated cycleway in the median area. Figure 9.27 shows how a standard two-phase signal could be combined with dedicated wait areas for turning bicycles in order to make both BRT and bicycle movements safe and efficient.

Other possible roadway configurations are also possible. Cycleways along the curbside are common in many cities.

Fig. 9.23 and 9.24
In Chinese cities such as Xi'an (upper left photo) cyclists are given designated waiting areas from which they have priority access to crossing the street. Likewise, in the UK (lower photo), a priority bicycle stopping area is placed ahead of the stopping line for motorised vehicles.
Left photo by Karl Fjellstrom
Right photo by Lloyd Wright

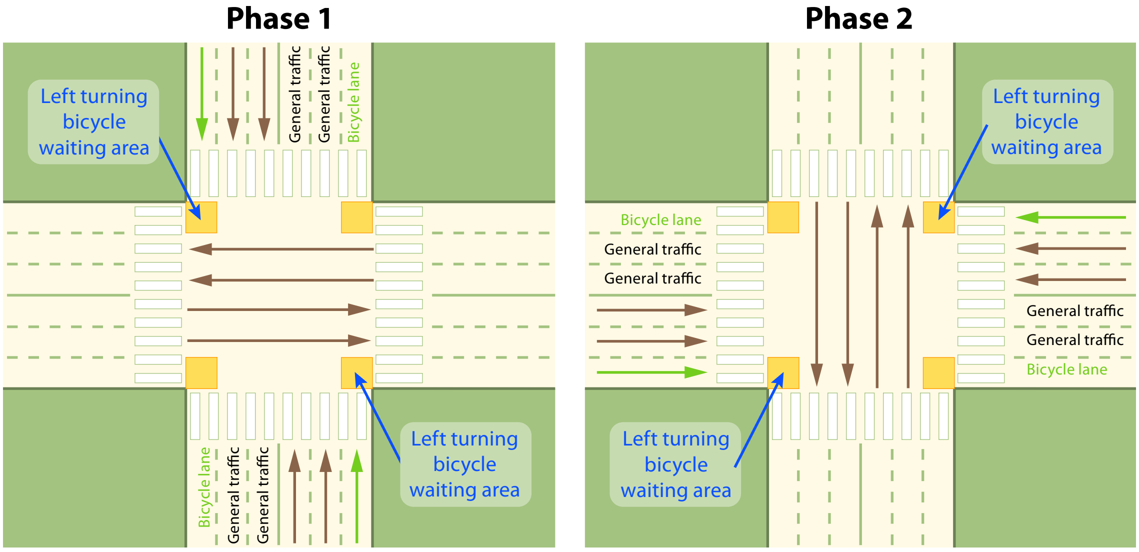


Fig. 9.25
Schematic of the dedicated waiting area utilised for bicycles wishing to make left turns in Xi'an.

Fig. 9.26
A dedicated green phase for crossing cyclists is another effective solution as shown in this example from Rio de Janeiro.
Photo by Lloyd Wright

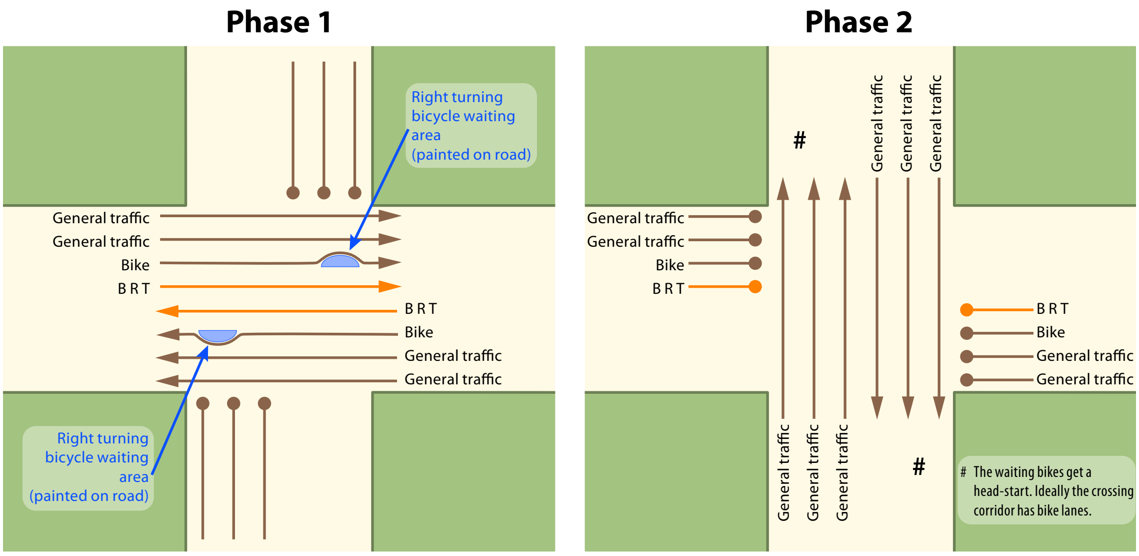


Fig. 9.27
A median cycleway and median busway can an effective solution to provide safe and efficient movements for both modes. In this case, a priority wait area for bicycles helps cyclists to get a head start over motorised vehicles in terms of negotiating a turn.

9.3 Designing for BRT turning movements

"To everything—turn, turn, turn
There is a season—turn, turn, turn
And a time for every purpose under heaven."
—The Byrds, 1965

While route simplification and organisation may to an extent minimise turning movements for BRT vehicles, some turning is necessary. By developing BRT routes with turns, easy platform transfers for the customers are made possible. Thus, turning movements by BRT vehicles can be an integral part of designing an effective overall route structure. As the BRT system expands and provides an increasingly dense network of lines, the connections between these lines become more complex. As BRT systems grow, there will be a growing number of BRT trunk corridors that cross one another.

The costs of not allowing turning movements by BRT vehicles are quite evident, especially in terms of customer convenience. Quito's three BRT corridors (Trolé, Ecovía, Metrobus-Q) all operate as independent corridors, despite each intersecting one another at several points in the city. At one of the critical intersections between two intersecting BRT corridors in Bogotá, customers must transfer by negotiating through stairs and an underground tunnel (Figures 9.28 and 9.29). In both these examples, allowing turning movements by the BRT vehicles could have permitted simpler and more convenient platform transfers for the customer. Further, the cost of constructing connecting pedestrian tunnels can add much to the overall infrastructure costs of the system.

The main problem with allowing all turning movements from within the BRT corridor is the increase in system complexity and the possible need for several additional signal phases. If the BRT corridor is built without any turns, the standard four phase intersection signal phasing shown functions well (Figure 9.30). In this case, customers will need to use an underground tunnel or a pedestrian overpass to transfer from one corridor to the other.

Fig. 9.28 and 9.29
A tunnel is used to connect two intersecting corridors in Bogotá. However, for many, making a transfer of this type imposes physical hardship.
Photos by Lloyd Wright

However, in order to facilitate transfer-free travel or even platform transfers, BRT turning movements from one corridor to another are desirable. When BRT vehicles turn, though, several problems emerge. First, BRT vehicles

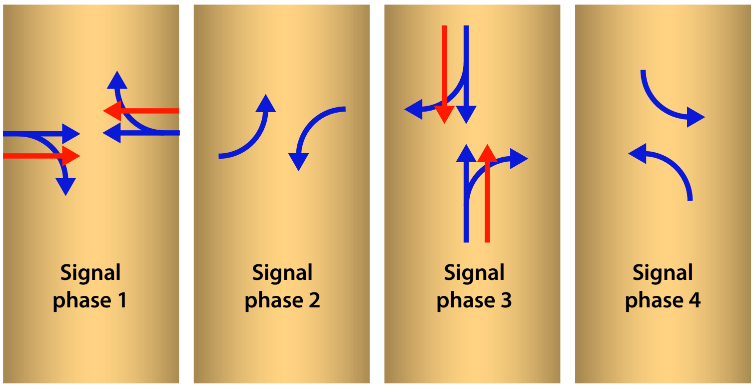


Fig. 9.30
In the case of two intersecting BRT corridors, a standard four-phase signal configuration can work if the BRT vehicles do not require any turning movements. In this example, BRT vehicle movements are represented by the red arrows.

turning right will conflict with mixed traffic wishing to go straight. One can add an additional signal phase to accommodate right turning buses and right turning mixed traffic only, but it adds a signal phase in both directions, increasing the signal phases to six.

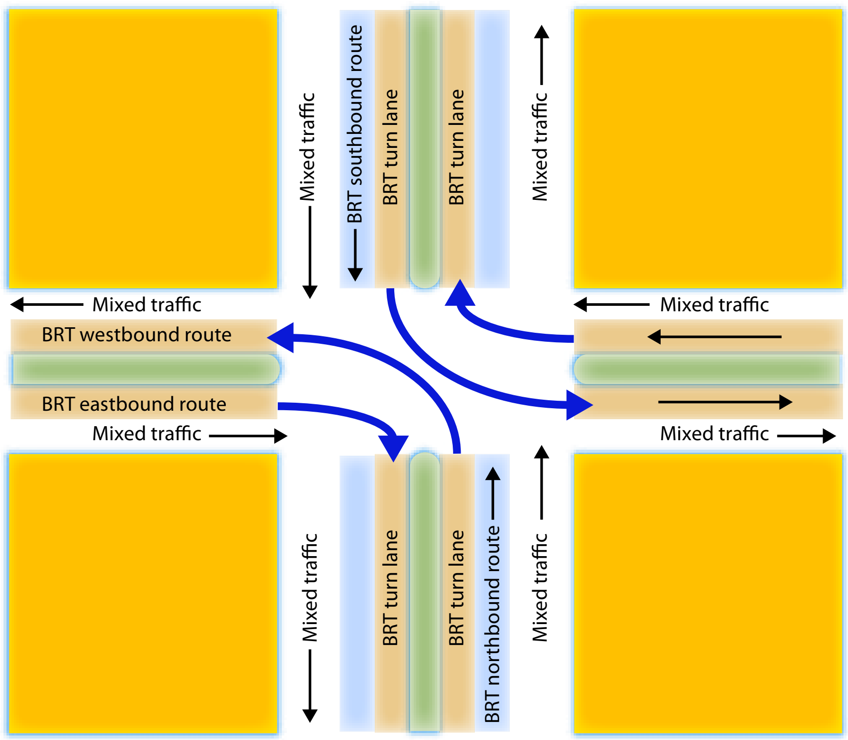
The second problem is that if there is only one lane for the BRT at the intersection and more than one bus tends to be at the traffic light during any given signal phase, then congestion may occur. If the first bus in the queue is wishing to go straight, it will have to stop during the right turn and left turn signal phase, so all buses behind that one in the queue are forced to wait an entire signal phase to clear the intersection.

However, as will be discussed below there are solutions to each of these problems. For example, by restricting private vehicle left turns (or right turns in a British-style system), then all BRT turning movements can be handled in a simpler three-phase signal system. Alternatively, limiting the number of turning permutations for BRT vehicles can help to eliminate any conflicts with turning private vehicles. By adding a dedicated turning lane for BRT vehicles, the problem of turning congestion can also be resolved.

There are several solutions to this basic problem, and the appropriate solutions will depend on the budget available, right of way available, the number of vehicles in the BRT system and their turning volumes, and the level of mixed traffic and its turning volumes. The optimal solution will be quite location specific and it is recommended that each intersection be evaluated and optimised separately. Five different options are presented in the following sections:

1. Dedicated turning lane and additional signal phase for BRT vehicles;
2. BRT vehicles operating in mixed traffic turning lane;
3. BRT turning movement prior to the intersection;
4. Conversion of intersection into roundabout
5. Queue jumping signalisation for BRT vehicles.

Fig. 9.31
Configuration for a system with a fully dedicated BRT turning lane.



9.3.1 Dedicated turning lane for BRT vehicles

A dedicated turning lane for BRT vehicles has the advantage of keeping the BRT vehicles in controlled space at all times. This arrangement may require an additional signal phase if there was no previous left-turn phase (or right-turn phase in a British-style system). Otherwise the dedicated turn would take place at the same time that the mixed traffic is allowed to turn left.

Possibly the greatest challenge to this configuration is finding the physical space to place the additional turning lane. The roadway would likely to have to accommodate at least 5 lanes (Figure 9.31). If two lanes of mixed traffic is to be maintained for straight car movements in each direction, then 7 lanes of space would be required. Additional lanes would also be

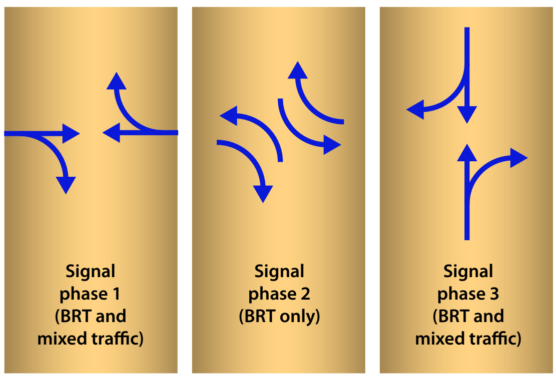


Fig. 9.32
In order to permit the BRT turning movements suggested in Figure 9.31, a three-phase traffic signal would be required.

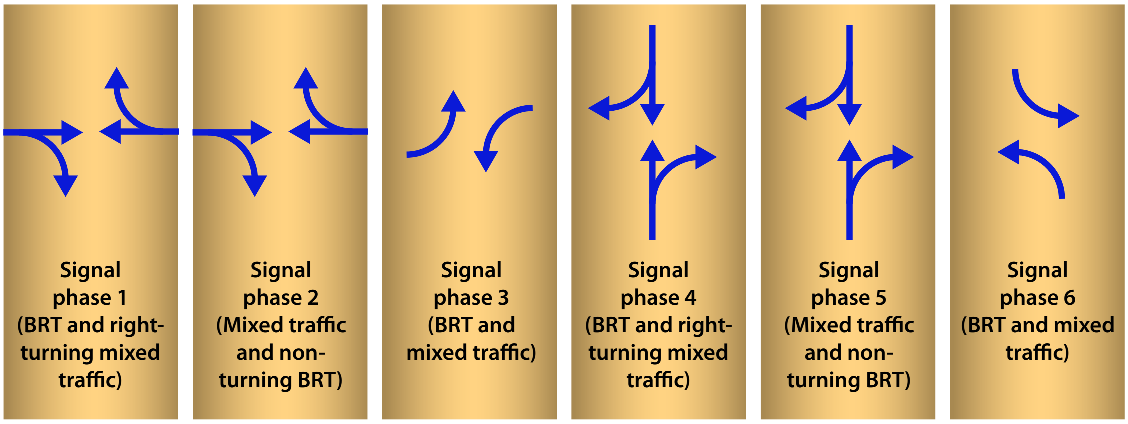


Fig. 9.33
To permit a full range of both BRT and mixed-traffic turning movements, a total of six signal phases would be required.

required if left turn movements were permitted for mixed traffic vehicles.

The configuration suggested in Figure 9.31 would require a three-phase traffic signal as indicated in Figure 9.32. This option is used in some BRT systems, and a variation of this solution is being discussed for Delhi but is meeting resistance from the traffic police.

In this case, it is important to note that not all turning permutations need to be provided for the BRT system. Instead, only one turn from each corridor to the other is required to give full access to all route permutations. This flexibility occurs due to the existence of a single median station. A southbound vehicle turning left will give passengers access to both the eastbound and westbound routes. Eastbound passengers will simply remain on board and continue along the corridor. Westbound passengers will undergo a platform transfer at the first station and reverse direction with a westbound vehicle. In designing this option, one would choose the highest demand routes to receive the transfer-free routing. In this scenario, one could technically also allow left turn movements for mixed traffic vehicles for traffic initiating the turn from north-south axis.

The complexity of dedicated turning lanes obviously increases as turning options for both BRT vehicles and mixed traffic vehicles increase. In the extreme of permitting all BRT turning options and all mixed traffic turning options, then a total of six traffic signal phases would be required (Figure 9.33). This number of phases clearly holds disadvantages in terms of waiting times for both BRT and mixed traffic movements.

Another alternative is to provide the dedicated turns through grade separated infrastructure. Bogotá utilises both underpasses and overpasses to provide dedicated turning infrastructure to BRT operations at its 80th Street-NQS interchange (Figure 9.34). While grade separation can be a highly efficient mechanism for facilitating free-flow turning, it can also be costly. The time saved to BRT customers and mixed traffic vehicles must be weighed against the cost of the underpass or flyover.

9.3.2 Mixed traffic operation

In this scenario, all turning BRT vehicles must leave the dedicated busway and enter mixed-traffic lanes. Thus, a left-turning BRT vehicle will leave the busway and directly enter the left-turn lane for cars. A right-turning BRT vehicle must leave the busway and merge to the right of the street. Once the turning BRT vehicles have left the intersection area they re-enter a busway.

Fig. 9.34
At the major intersection of TransMilenio's Calle 80 (80th Street) corridor and NQS corridor, a set of underpasses, a roundabout, and an overpass helps facilitate exclusive turning movements for BRT vehicles.
Photo courtesy of Eduardo Plata and Por el País que Queremos (PPQ)

Fig. 9.35

In Kunming, turning BRT vehicles leave the busway and enter a mixed-traffic lane to finalise the turning movement.

Photo courtesy of ITDP

This technique is the most common solution that has been used in many of the "open" BRT systems like in Kunming, China, and is being planned on several "direct services" BRT systems (Figure 9.35). If there is no physical separation of the busway, the merge with the mixed traffic can happen anywhere in the proceeding block. If there is physical separation, it must occur at the previous intersection, or a slip lane must be provided.

From a signal phase standpoint, this option is the easiest to implement, as it does not require changing the signal phase, and does not require any major new infrastructure. However, this option does present a serious disadvantage in terms of congestion delay for the turning BRT vehicles. Further, if the mixed-traffic congestion is heavy, the BRT vehicles attempting to turn may not be able to readily leave the busway, and thus can cause delays to all BRT vehicles, even those vehicles continuing in a straight routing. The BRT vehicle turning right has particular challenges since it must essentially cross all mixed-traffic lanes both before and after the intersection. Attempting these lane changes is particularly difficult if the system is using 18.5-metre articulated vehicles or 24-metre bi-articulated vehicles.

Any time BRT vehicles must leave exclusive busway operation and enter mixed-traffic lanes the system losses a certain amount of psychological status with the customer. Mixed-traffic operation makes the system much more akin to a conventional bus system rather than a highly-efficient mass transit system. Once vehicles start operating in mixed traffic, the customer's "mental map" of the system becomes more uncertain. Such confusion does much to discourage system use by occasional and discretionary system users.

9.3.3 BRT vehicle turning onto secondary street

Sometimes it is desirable to allow a special bus-only left turn at a smaller intersection just before a major intersection (Figure 9.36). In this case, no special BRT turning phase is required at the more congested intersection. The BRT vehicle will operate on secondary mixed traffic streets or on a dedicated lane on the secondary streets until it rejoins the busway. This option requires the availability of usable secondary streets, which is not always the case.

9.3.4 Convert intersection into roundabout

One approach that is being tested for BRT systems being developed in Ahmedabad and Jinan is to convert a standard four phase intersection into a two-phase signalized roundabout. The exclusive BRT busway terminates approximately 50 metres prior to the intersection with the BRT vehicles entering mixed traffic at that point.

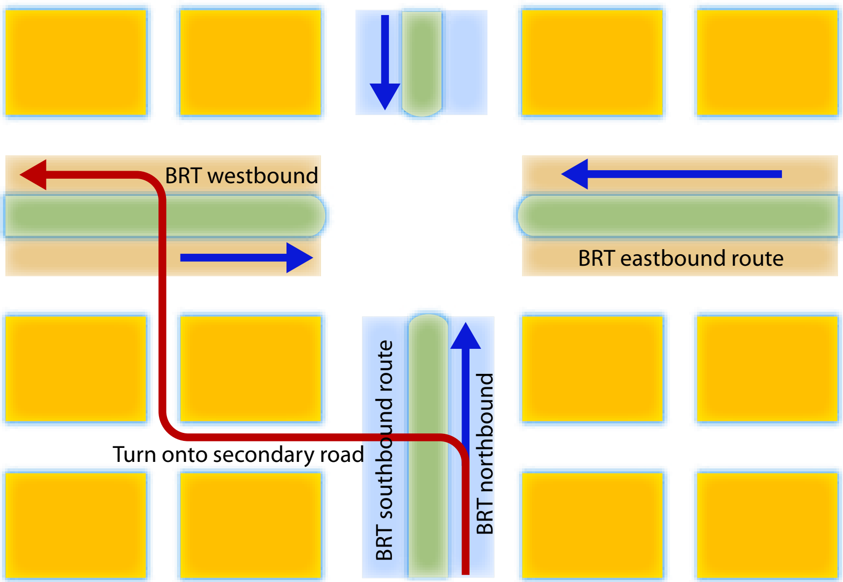


Fig. 9.36

In this scenario, the BRT turning movement is made prior to the main intersection. The BRT vehicle temporarily operates on the secondary road network.

This approach essentially turns the junction into a grid of one-way streets. It requires a fairly large amount of right-of-way at the junction. However, in many developing-nation cities, such right-of-way is available but underutilised.

Figure 9.37 indicates how the junction between two major boulevards can be turned into a two-phase traffic circle by creating a kind of mini-grid of one-way streets. At low traffic volumes, the BRT buses enter mixed traffic prior to the intersection. A series of queuing areas (marked as "A", "B", "C", and "D" in Figure 9.37) help stage vehicle flows through the roundabout.

Figure 9.38 outlines the vehicle movements for first signal phase for this roundabout conversion. This example is given from the perspective of a British-style road configuration. All east-bound BRT vehicles and mixed traffic vehicles that are making right-hand turns would pass through the intersection and queue in area "C" at a traffic light. All east- and west-bound traffic can proceed straight. All vehicles making left-hand turns can proceed. All west-bound traffic would pass through the intersection and queue in area "B".

In the second signal phase, all northbound and southbound traffic can proceed straight, all left hand turns can proceed, and all right turning traffic would queue in areas "A" and "D" (Figure 9.39).

This solution will work up to the point where the amount of space in areas "A", "B", "C", and "D" is sufficient to accommodate all the turning traffic. Equations 9.5 and 9.6 define the calculations for the required and available queuing space.

Equations 9.5 and 9.6 Available and required space for queuing area

$$\text{Available static area capacity (pcu)} = \text{Length} * \text{Width} / \text{Unitary pcu practical space}$$

$$\text{Required capacity (pcu)} = \text{Turning volume (pcu)} * \text{Cycle time}$$

In equations 9.5 and 9.6, the calculated units are in passenger-car units (pcu). In order for the configuration to function, the available space must be equal or greater than the require space.

The following scenario provides an example of calculating the required and available capacity of the proposed roundabout queuing space.

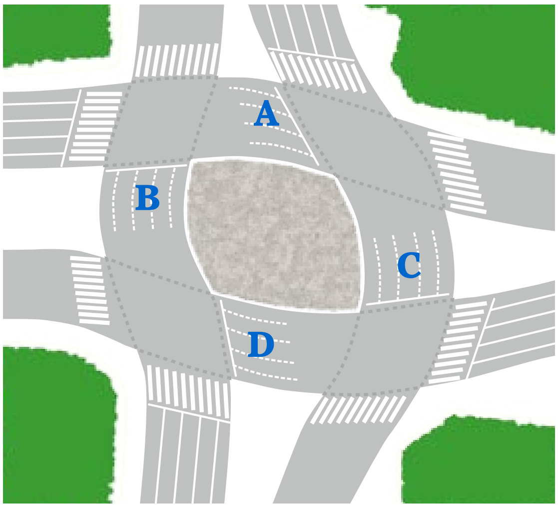


Fig. 9.37
In this scenario, the intersection is converted to a roundabout with vehicle queuing areas at points "A", "B", "C", and "D". The BRT vehicles enter mixed traffic just before the intersection and move through the intersection with a two-phase signal.

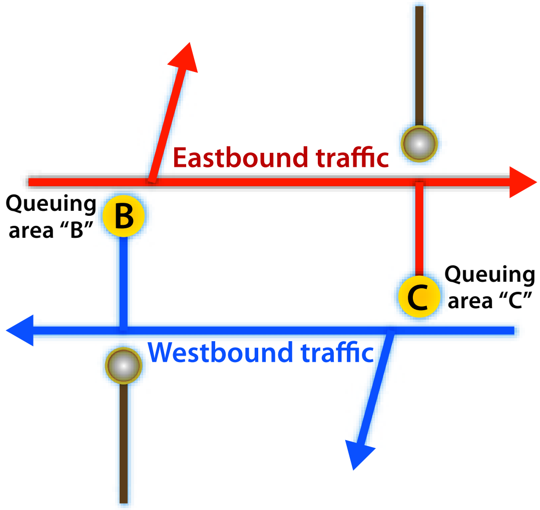


Fig. 9.38
Vehicle movements for signal phase 1.

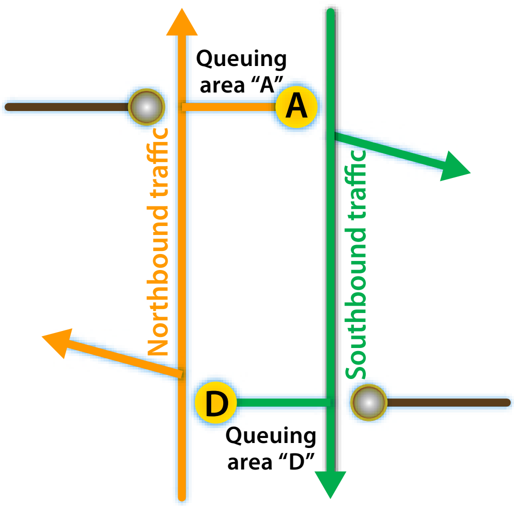


Fig. 9.39
Vehicle movements for signal phase 2.

Turning movement = 540 pcu/hour = 0.15 pcu/sec
Cycle time = 90 sec
Required capacity = 0.15 * 90 = 13.5 pcu

Unitary pcu space = 3 m * 5 m = 15 m^2

Length = 30 m
Width = 12 m
Available capacity = (30 m * 12 m) / (15 m^2/pcu) = 24 pcu

In this case, the available capacity is greater than the required capacity (24 pcu ≥ 13.5 pcu), so the proposed roundabout conversion could function.

When the number of mixed traffic vehicles and BRT vehicles rises to the point that areas "A", "B", "C", and "D" are too small to accommodate the number of turning vehicles, turns should be restricted for mixed traffic but not for BRT vehicles. Effectively, the queuing areas "A", "B", "C", and "D" would be reserved for BRT vehicles.

Cycle times on a signalised roundabout of this type should not be very high and never manually operated otherwise it would collapse by the inevitable universal tendency of manual operators to employ long cycles.

9.3.5 Queue jumping

"An Englishman, even if he is alone, forms an orderly queue of one."

—George Mikes, writer, 1912–1987

The signal system can be utilised to give BRT vehicles a head start on turning movements prior to private vehicle turning movements. In this case, a dual traffic signal is utilised for each direction of travel: 1. One traffic signal is located at the intersection; 2. Another traffic signal is located approximately 30 to 50 metres prior to the intersection. At the traffic signal prior to the intersection, the BRT vehicles on the busway would receive a green signal approximately 10 seconds prior to the green signal for the mixed traffic (Figure 9.40). During this head start, the BRT vehicle would be able to exit the busway and cross to the other side of the street.

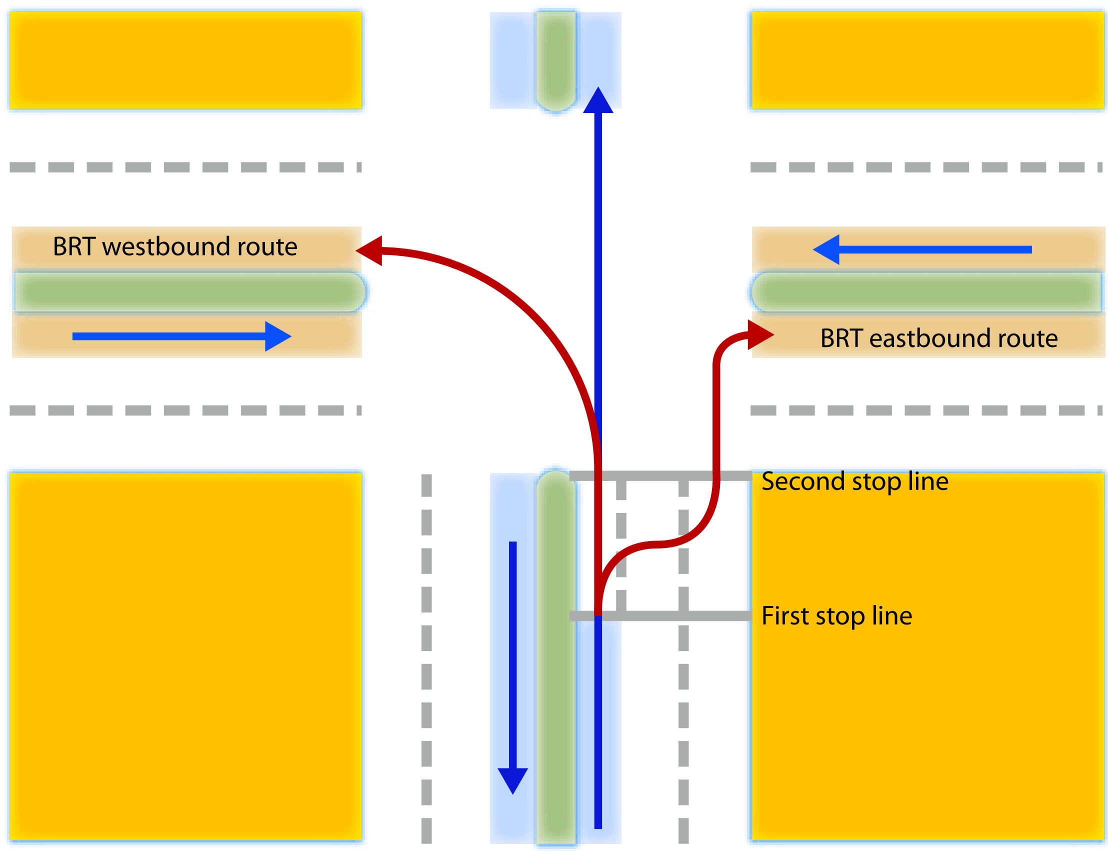


Fig. 9.40
While mixed traffic vehicles are held for an extra 10 seconds at the first traffic signal stop, BRT vehicles are given a queue-jumping head start.
Image adapted from TCRP Report Number 90 (Levinson *et al.*, 2003b, p. 4-13)

9.4 Station location relative to the intersection

"The engineer's first problem in any design situation is to discover what the problem really is."

—Anonymous

One of the more contentious issues among BRT planners is the optimal location of the station relative to the intersection. Intersection and station design should generally be optimised to minimise the travel time of the majority of the customers. The station location in relation to the intersection will affect mixed traffic flow and speed, BRT system flow and speed, pedestrian travel times, and the right-of-way needed for the BRT system. Because conditions vary from intersection to intersection, it is generally advisable to find an optimal solution for each intersection rather than to presume a single solution will always be optimal. The greater amount of information the planning team has available regarding movements and demand, the easier it will be to optimise this decision for all modes of transport.

The following station locations are possible:

- At the intersection before or after the traffic signal;
- At the intersection but before the traffic signal in one direction and after it in the other direction (if using a split station configuration);
- Near the intersection but not at the intersection;
- Mid-block;
- Under (or over) the intersection.

9.4.1 Stations on each side of intersection

The normal justification for putting the bus stop at the intersection is that it reduces walking times for transferring passengers and passengers with destinations on perpendicular streets. The importance of this option will vary with pedestrian transfer volumes and the distribution of pedestrian destinations. As noted elsewhere, if using platform transfers, then customer transfers between nearby stations will be eliminated. In general, designing for platform transfers is far superior to forcing customers to walk across an intersection to another station. The practice of intersection transfers is typical in European tram systems where linear routing structures frequently cause heavy transfers at major intersections.

Fig. 9.41
In Taipei, the location of the stations prior to the intersection avoids the problem of BRT vehicles blocking the intersection. However, this configuration may mean that some vehicles will miss the green phase.
Photo courtesy of Jason Chang

For BRT systems with curb-side boarding, a separate station platform is needed in each direction. In order to maintain a more constant right of way, the standard practice is to put the stations for one direction on one side of the intersection, and the bus stop for the other direction on the other side of the intersection. System designers therefore usually put the stations before the intersection in both directions or after the intersection in both directions. However, this practice does have a substantial disadvantage for passengers wishing to change directions. These customers must make a difficult walk across the intersection.

There is an emerging consensus that in most cases placing the stations before the intersection, as in Taipei (Figure 9.41) increases the chances that boarding and alighting time can overlap with the traffic signal red phase, but the benefit may vary with local circumstances. However, in this configuration a single boarding and alighting delay can prevent the other BRT vehicles behind the first vehicle from clearing the intersection, forcing them to miss the green signal phase.

Alternatively, placing the stations after the intersection presents a different set of issues. This configuration does allow the station platform to be used as a physical barrier to help to ensure that mixed traffic does not enter the busway. The location of the stations after the intersection also sends a clearer visual clue to boarding passengers which direction the vehicle is likely to go.

However, if the system operates as an "open" system and there is a tendency for congestion on the busway, a station after the intersection runs the risk that the buses could back-up into the intersection and block other traffic. This configuration could also mean that BRT vehicles will be forced to wait on the opposite side of the intersection and therefore miss an entire green phase. This situation occurs in the relatively congested busways of Kunming (Figure 9.42). For this reason, there is a tendency for some designers to prefer the placement of the station before the intersection.

If the station is before the signal, there is a chance that the BRT vehicle will arrive at the station just at the optimal moment, when the signal is turning red. If the BRT vehicle arrives when the signal turns red, all the boarding time will occur on red time. If this particular timing was always the case, then there are obvious travel time savings since station dwell time coincides with the period of the red signal phase.

However, there is as good a chance that the bus will pull into the bus stop just as the signal is turning green. In this case, all the boarding and alighting will take place during the green phase of the signal. Since the buses arrive at random times, there will be occasions when this occurs.

Fig. 9.42
In Kunming, the busway operates with high volumes and stations located after the intersection. These conditions may cause negative impacts: 1.) Buses may end up blocking the intersection if station area is occupied; or 2.) Buses may not be able to cross the intersection during the green signal phase.
Photo courtesy of the Municipality of Kunming

9.4.2 Single median station near intersection

In high-quality "full" BRT systems a single median station is the optimum solution. Such configurations allow customers to make comfortable platform transfers and this configuration also greatly simplifies routing options. Further, the construction of a single median station is generally less costly than constructing two side-aligned stations per direction.

If the median station is placed near an intersection, then the question of before or after the intersection is irrelevant. By definition, the platform(s) of one direction will be before the intersection and the platform(s) of the other direction will be after the intersection. If congestion for either the BRT system or mixed traffic is not a concern, then locating the BRT station at the intersection is not problematic.

9.4.3 Locating the station away from the intersection

In situations whether either mixed traffic volumes or bus volumes are nearing saturation, it is generally recommended to separate the BRT station and the intersection. If, for the sake of pedestrian convenience, the design team is considering placing the BRT station directly at the intersection anyway, the degree of saturation of the busway should be tested on an intersection by intersection basis. In the case of using the preferred single median station configuration, there is not likely to be any significant pedestrian advantage to an intersection location. In the central areas of a city, mid-block destinations may well be as important as intersection destinations.

Separating the station location and the intersection minimises the risk that BRT vehicles will be backed up at the station, which will inhibit the functioning of the intersection and the functioning of the station. If these two potential bottlenecks are co-located, the risk of mutual interference between the station and the intersection increases (Figures 9.43 and 9.44).

If the BRT system has physically defined stopping bays like in TransMilenio or Curitiba, there is a risk that buses queuing to pass through the intersection will also obstruct the station, and passengers will be unable to board and alight until the buses in front clear the intersection. This problem is not as serious in "open" BRT systems without clearly designated stopping bays, but such systems force customers to find their appropriate bus rather than the bus finding the customers. In such systems, customers will have to run up and down the platform to locate and then board their bus. This chaotic boarding process not only creates stress for the customer but it also increases boarding times.

9.4.3.1 Station to intersection interference levels

Estimating the level of station to traffic signal interference

For an accurate assessment of the potential conflict between the intersection and a nearby station, micro-simulation modelling of the intersection would be ideal. However, proper micro-simulation modelling requires data generated by a fully calibrated traffic demand model, which is sometimes not readily available. As such, it is worth doing some basic calculations in order to approximate the likelihood of possible station-intersection bottlenecks.

It is generally advisable to investigate the degree to which the location at the intersection increases the time that BRT vehicles are blocking the station, or the level of saturation of the station.

As noted in Equation 9.7, the amount of interference between the station and the intersection depends first of all on the relationship (KR) between the time of the red signal phase (TR) and the average stop time per bus at the bus stop (TB).

Equation 9.7 Ratio of stopping time to red signal time

$$KR = TR / TB$$

Where:

KR = the ratio between the average stopping time for buses at the station and the time of the red signal phase

TR = amount of time of red signal phase

TB = average stopping time at the station

As a general rule, the higher the KR value, or the more the red signal time exceeds the average boarding time per bus, the greater the risk that traffic signal interference will saturate the station.

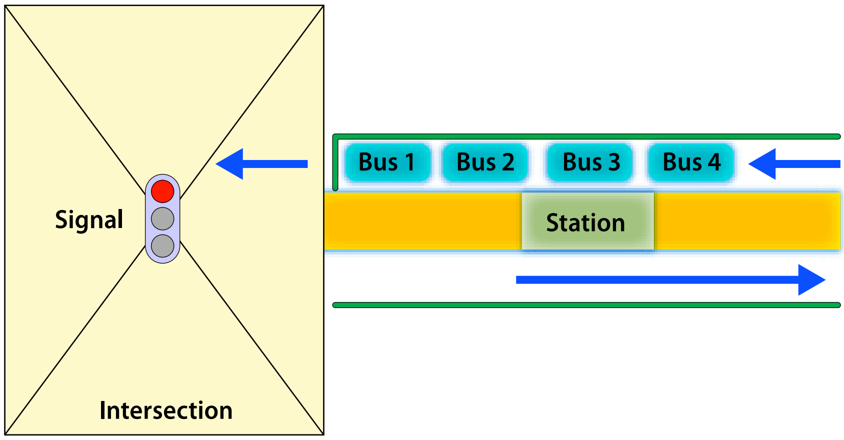


Fig. 9.43
For the direction of the BRT system that stops at the station before the intersection, there is a risk that vehicles will be delayed due to the signal phase.

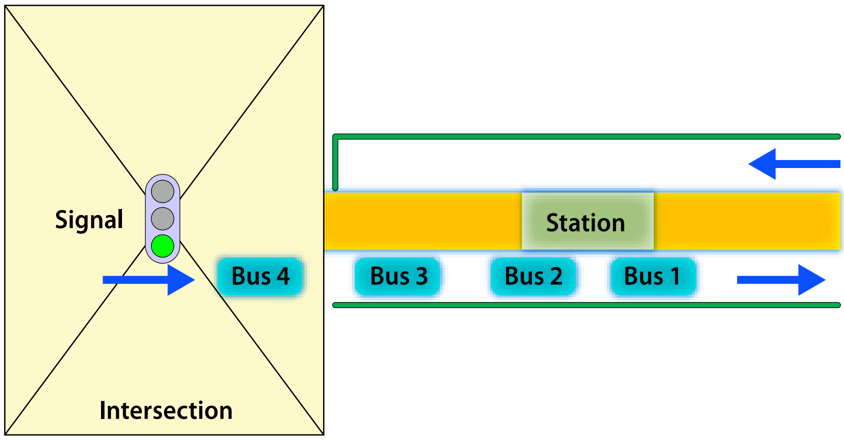


Fig. 9.44
For the direction of the BRT system that stops after the intersection, there is a risk that vehicles make back up into the intersection and block traffic.

Roughly, the combination of the station's normal saturation and the additional saturation caused by traffic signal interference will tell one the degree of busway saturation. As a general rule, it is best to design the busway with a saturation level of under 0.4 at the station, meaning that the station is only occupied 40 percent of the time. Equation 9.8 shows how the level of saturation varies with different ratios (KR) of red signal time to vehicle boarding times.

Equation 9.8 Busway saturation

$$Xsb0 = x * TC / (TC - TB * KR))$$

Where:

Xsb0 = Saturation at the station resulting from both normal busway saturation and the signal interference when there is "0" distance between the bus stop and the intersection

x = Normal saturation of the station without signal interference

The factor "x" involves a complex calculation, the derivation of which was illustrated earlier in this chapter. For this section, it will always be assumed that the normal busway saturation has been optimised, and station saturation without signal interference has been kept constant at 0.35, which will rarely congest.

TC= Total cycle time
TB = Average stopping time at the station

In equation 9.8, the variables of "TC/(TC-TB)" shows the ratio of the total signal phase to the average bus stopping time. For example, if the signal phase is 60 seconds, and the average stopping time is 30 seconds, then 60/(60-30) is 2. In this case, the total signal phase is twice as long as the average stopping time per bus at the station.

The average bus stopping time TB is derived as indicated in Equation 9.9.

Equation 9.9 Average bus stopping time

$$TB = X / F * 3600$$

Where:

F = Frequency in buses per hour

3600 = seconds in an hour.

Since X has been assumed to be a constant of 0.35, this example produces the following result:

TB = 0.35 / F * 3600

Finally, the factor "KR" shows that the total saturation of the busway depends not only on the relationship between the total signal phase and the bus stopping time, but also on the relationship between the time of the red signal phase (TR) and the average stopping time per bus at the station (TB). The precise relationship between the bus stopping time, the total signal phase, and the total red time, will vary depending on whether the average bus stopping time (TB) is shorter or longer than the red signal phase (TR), which is reflected in the factor "KR" above.

Interference level when bus stopping time is shorter than red signal phase

The concern about interference is most acute when the bus stopping time (TB) is short and the red phase (TR) is longer, or of similar magnitude. Interference is only of limited concern if the red phase is very short.

Looked at another way, the saturation of the station when the station and the intersection are co-located, will increase in relation to the average time that the boarding and alighting (TB) process overlaps with the green signal phase (Tv).

If the bus stopping time is shorter than the red signal time, then in the most extreme case the station can mostly only function during the green signal phase. For example, in a system with pre-paid platform level boarding, and designated stops for the bus doors, and an intersection with very few passengers boarding and alighting, it is quite possible that the average stopping time per bus could be quite low, as low as 10 seconds. In this case, the risk of interference between the bus stop and the intersection is extremely high.

During the red phase, the bus pulls up, and after only ten seconds, boarding and alighting is completed. After a few seconds, the next bus pulls up behind the first bus, but it cannot board and alight because the station is still occupied by the first bus waiting at the traffic light. A third and a fourth bus may pull up, during which time none of them can board or alight because the first bus is still facing a red signal. In this case, the level of interference between the signal and the bus stop is at a maximum.

Therefore, if

TB < TR

Then:

Xsb0 = x * TC / (TC – TR + To)

Where:

Xsb0 = Saturation at the station resulting from both normal busway saturation and the signal interference when there is "0" distance between the station and the intersection

x = Normal saturation of bus stop without signal interference
TC = Total cycle time
TR = Total red time
To = The average time that the boarding and alighting process overlaps with the red signal phase
x = 0.35

If the bus stopping time is less than the red time at the traffic light, the impact of the conflict between the signal and the station on the system's saturation can be estimated by assuming that half of the boarding time will take place during the red time and half will take place during the green time. This assumption will not be exact, but it will give a good indication of the risk of saturation.

Mathematically, therefore,

To = 0.5 * TB

Where:

0.5 = the probability that boarding and alighting will take place during the red phase.

TB = x / F * 3600

In this case, calculating the saturation of the station when faced with interference from the traffic signal, the following formula can be used:

Xsb = x * TC / (TC - TR + (0.5*TB))

Since the equation varies depending on the ratio of red time to stopping time (KR), the equation below shows how KR enters into the equation:

Since KR = TR/TB, then TR = TB*KR, so the above formula can also be written as follows:

Xsb = x * TC / [TC- (TB * KR) + (0.5*TB)]

Therefore, for the conditions in which the boarding and alighting occurs half during the red signal phase and half during the green signal phase, Equation 8.19 becomes:

Xsb = x * TC / (TC - TB * (KR - 0.5))

Box 9.1 provides an example of applying this equation for conditions in which there is a short boarding and alighting time relative to the read signal phase.

Box 9.1: Calculating station to intersection interference with a long red phase cycle

This example assumes that the vehicle stopping time occurs equally between the red and green signal phase.

Xsb0 = x * TC / (TC - TR + (0.5 * TB))

x = 0.35
TC = 700 seconds of total cycle time
TR = 500 seconds of total red time
TB = 10 seconds (average bus stopping time)

Xsb0 = 0.35 * 700 seconds / (700 seconds – 500 seconds + 0.5 * 10 seconds)
= 1.195

In this hypothetical example the station would operate on just the 200 seconds of green, but not on the 500 seconds of red, because just some seconds after the red phase begins the bus will finish boarding, but it will obstruct access to the bus stop during the entire 500 seconds of red.

Thus, at a value of 1.195 the high saturation leads to considerable congestion of the busway.

Interference levels with a short red phase

If the red signal phase is very short relative to the boarding and alighting time, then even if the signal changes to red just as boarding and alighting has been completed, it will be a short time before the light is green again. Thus, there is less concern about interference between the station and the intersection.

Based on empirical observation, while not exact, it is reasonable to assume that if the bus stopping time is greater than or equal to red signal phase, the formula for calculating the level of total saturation should be changed to reflect the lower chance of interference. Empirically, the following formula is generally a reasonable predictor of interference.

If TB ≥ TR,

Then:

$$Xsb0 = x * TC / (TC – TB * (KR^2 / 2))$$

Since KR = TR / TB,

$$Xsb0 = x * TC / (TC - TR^2 / 2TB)$$

Box 9.2 provides an example of relative interference levels when the red phase time is short.

Box 9.2: Calculating station to intersection interference with a short red phase cycle

In this example, the red phase cycle time is relatively short when compared to the vehicle stopping time.

TR = 15 seconds of red phase
TB = 40 seconds of vehicle stopping time
TC = 30 seconds full signal phase
x = 0.35

Xsb0 = 0.35 * 30 / (30 - 152 / (2 * 40))
= 0.386

In this case, because the red phase is quite short, there is fairly minimal risk that the traffic signal will disrupt the functioning of the bus stop, so saturation increases only marginally, from 0.35 to 0.386.

Fig. 9.45

A mid-block station location in Seoul allows greater right-of-way width for the station area.

Photo courtesy of the City of Seoul

9.4.3.2 Maximising right-of-way with mid-block stations

Another principal advantage of placing the BRT stop at some distance from major intersections is that it is generally a more optimal way of using a limited right of way. BRT systems consume the greatest amount of right-of-way at the station area. This is not only to provide as wide a station platform as possible, it is also sometimes necessary to provide an additional passing lane.

For a BRT system, the main congestion point is typically the station area. For mixed traffic, the main congestion point is typically the intersection. For this reason, it is generally advisable to provide the maximum right-of-way to the BRT system at the station, and the maximum right-of-way for mixed traffic at the intersection. If these two functions are separated, then a fixed amount of right-of-way can be used. The same right-of-way used for dedicated mixed traffic turning lanes at the intersections can be used for passing lanes at the BRT station (Figure 9.45).

For example, at the bus stop, if bus frequencies are high and an overtaking lane is needed at each station, the extra width required will be around 12 metres. If the station is located at the intersection, these 12 metres will be difficult to supply while also providing 6 metres for left and right turn lanes for mixed traffic. Separating these functions will allow the same right of way to be used for the bus station at mid-block, and for left and right turn signals at the intersection. Figure 9.46 shows an application of this concept within a proposal for the Delhi BRT system.

9.4.3.3 Optimisation of station location when walking time is included

When pedestrian walking times are also considered, the optimisation calculation becomes somewhat more complicated. Optimising station location in terms of pedestrian walking times is location-specific, as it depends on the location of popular pedestrian destinations, the boarding and alighting passenger volumes, the passenger transfer volumes, the location of allowed pedestrian crossings, and the structure of the signal phasing.

The main bottleneck for pedestrians is the delay they face crossing the street, and the distance of the actual route between the station and their destination. The crossing time will be a function of the signal phase if the pedestrians are crossing at a signal and of the gaps in the traffic if they are crossing at non-signalised locations. The distance of the actual route will be affected both by the inherent location of the station in relation to popular destinations, and the places

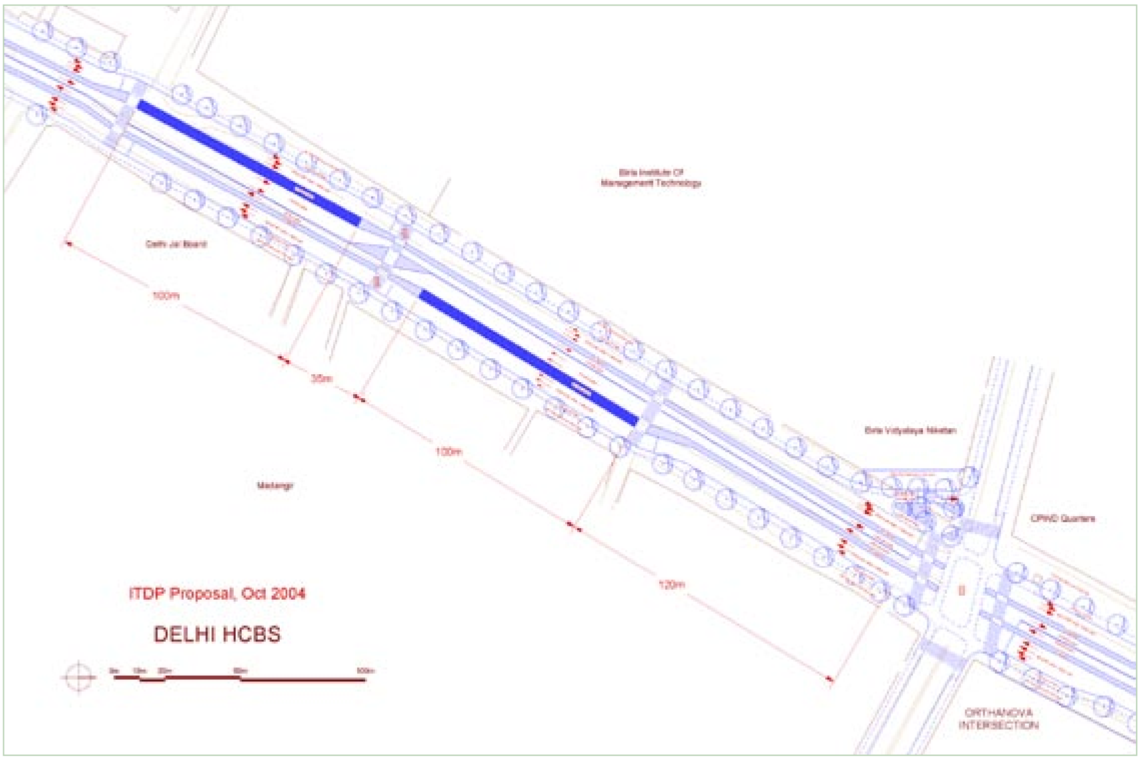


Fig. 9.46
In this proposed road layout for Delhi, the mid-block BRT stations are given additional right-of-way. However, at the intersections, right-of-way for mixed traffic vehicles is maximised.
Image courtesy of ITDP

where the pedestrian is able and allowed to cross the street safely.

Further, relevant pedestrian movements are not just confined to the area around the BRT station. Rather, consideration of a pedestrian's entire path must be considered, which may encompass an area of 1,000 metres or more from the station as well as several different street crossings.

To optimise station location for pedestrians with high precision would require labour intensive, site-specific analysis of the origin and destination patterns of boarding and alighting BRT passengers. These patterns would then have to be weighed against the impact that this decision has on the BRT system and on mixed traffic. If a highly complex case-specific analysis is not possible, some general rules can be applied to obtain a solid estimation of preferred station location:

- If mixed traffic turns are allowed, and turning volumes are high, and the number of boarding and alighting and transferring passengers is low, the BRT station should be situated far enough away from the intersection to avoid interference and to provide sufficient turning lane capacity.
- If a popular high volume pedestrian destination exists along the corridor, such as a commercial centre, school, or major office centre, proximity to this location may be more important than proximity to the intersection.
- If the system operates with the less preferred design of side-aligned stations, then stations may need to be located near intersections in order to facilitate transfers to perpendicular roads; this situation is not relevant to the preferred option of median stations since transfers are accommodated at the platform through turning movements of the BRT vehicles.
- If both turning vehicle volumes and BRT vehicle volumes are high and a key destination is located at the intersection, then a more detailed study should be carried out.

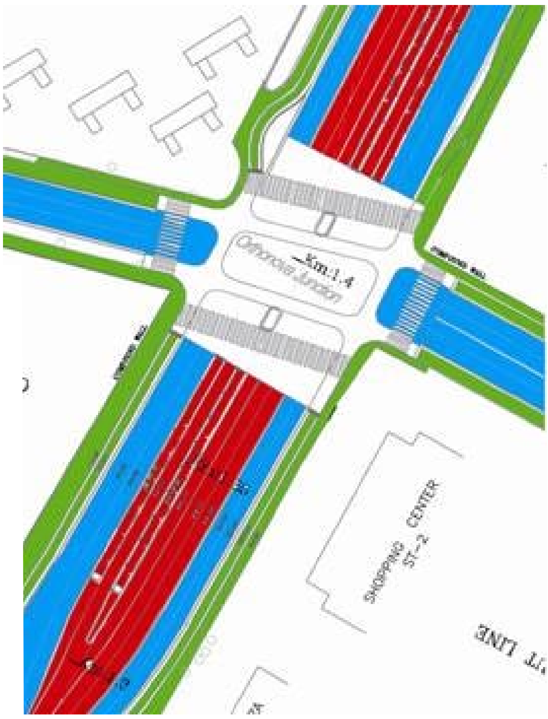


Fig. 9.47
Given the wide amount of right-of-way in this section of the Delhi BRT system, intersection section stations have been proposed in order to maximise pedestrian convenience.
Image courtesy of ITDP

If the BRT system does not require a passing lane to avoid congesting, there are no right-of-way constraints, and there are not high volumes of turning mixed traffic vehicles, then placing the station at the intersection can be an option to consider. If the BRT system has an "open" routing structure, where buses pass from the BRT system to mixed traffic streets, as a general rule, passenger transfer volumes will tend to be low. Proximity to the intersection is then less important.

Initial plans for the Delhi BRT system include four full bus lanes (two in each direction) and two full loading platforms at the intersection, consuming a total of six lanes (9.47). This configuration also includes two lanes of mixed traffic in each direction. As the existing right-of-way is extremely wide, and some turns will be restricted, it is possible to use this design. Analysis showed that placing the stations at the intersection was optimal from the perspective of pedestrian walking times. As this design has not yet been built, it has not yet been tested empirically. The designers in Delhi argued that location of the pedestrian crossing at the intersection was also likely to be safer and easier than if pedestrians have to cross mid block, though others argue that the complexity of vehicular movements at the intersection may make pedestrian crossing mid-block safer. The relative scarcity of research in this area makes the issue one for further study.

Detailed analysis requires a separate analysis of the different travel time impacts of different locations on each of the different types of trips: Pedestrian, BRT, and mixed traffic. To date, widely available micro-simulation models for the analysis of intersections have not been developed to handle the complexity of pedestrian and BRT movements that would need to be analysed. Thus, for the time being, simple spreadsheet analysis may be an appropriate evaluation tool.

If the situation is optimised including walking times, it is quite probable that along a BRT corridor, some stations would be located at mid-block, others at the intersection, and still others adjacent to major trip destinations. Furthermore, some compromise between pedestrian travel times and the vehicular travel times can generally be found. Stations do not need to be in the middle of the block to avoid interference with the intersection, they just need to be far enough away to avoid the conflict.

9.4.3.4 Calculating the minimum distance to avoid station—intersection conflicts

To avoid conflicts between station areas and intersections, a mid-block station location is not the only option. Of course, a mid-block location could be optimum, depending on the local destinations and pedestrian patterns.

In any event, it is useful to calculate the minimum distance that will avoid any likely conflict between BRT vehicle movements at stations and mixed traffic movements at intersections. The minimum distance can be simply determined by the amount of space required by queuing BRT vehicles. In the case of lower-volume BRT systems, queuing vehicles may not be an issue at all. In the case of higher-volume systems, then consideration of the possible bus queue at intersections and stations should be taken into account (Equation 9.10).

Equation 9.10 Calculating the minimum distance between stations and intersections

$$Dbs > Nbr * Lb$$

Where:

Dbs = Distance from the BRT station to the stop line of the nearest traffic signal

Nbr = Likely number of BRT vehicles to queue during the red phase of the traffic light

Lb = Average length of lane space consumed by the queuing BRT vehicles

The factor "Lb" consists of two factors: 1. Length of the BRT vehicle (L); and 2. Length

Box 9.3: Calculating the minimum recommended distance between the BRT station and the intersection

This example utilises data typical of an average city in India.

Nbr = Tr1 * Fb / (1 – (Fb / Sb)) / 3600

Tr1 = 50 seconds of red time at intersection
Fb = 200 buses per hour passing a particular intersection
Sb = 720 articulated buses per hour per lane could pass intersection if the signal were green all the time

Nbr = 50 * 200 / (1 – (200 / 720)) / 3600
= 3.8 buses

Because one cannot actually operate 3.8 buses, "Nbr" must be rounded to the nearest integer, so "Nbr" is equal to 4.

Lb = Length of BRT vehicle + Length of space between vehicles when stopped
= 18.5 metres + 1 metre
= 19.5 metres

Dbs > NBr * Lb
> 4 * 19.5
> 78 metres

Thus, based on the values presented in this example, the minimum recommended distanced between the BRT station and the intersection would be 78 metres.

of space between BRT vehicles when stopped (usually assumed to be 1 metre).

Equation 9.11 is then used to derive the number of BRT vehicles that will queue at the signal.

Equation 9.11 Number of BRT vehicles that will queue at the signal

$$Nbr = Tr1 * Fb / (1 – (Fb / Sb)) / 3600$$

Where:

Tr1 = Amount of red time placed on the BRT vehicles at intersection

Fb = BRT vehicle frequency per hour at the intersection

Sb = Bus lane capacity (usually 720 articulated buses/lane/hour or 950 standard buses/lane/hour)

3600 = seconds in an hour

Box 9.3 provides an example of calculating the minimum recommended distance between the BRT station and the intersection.

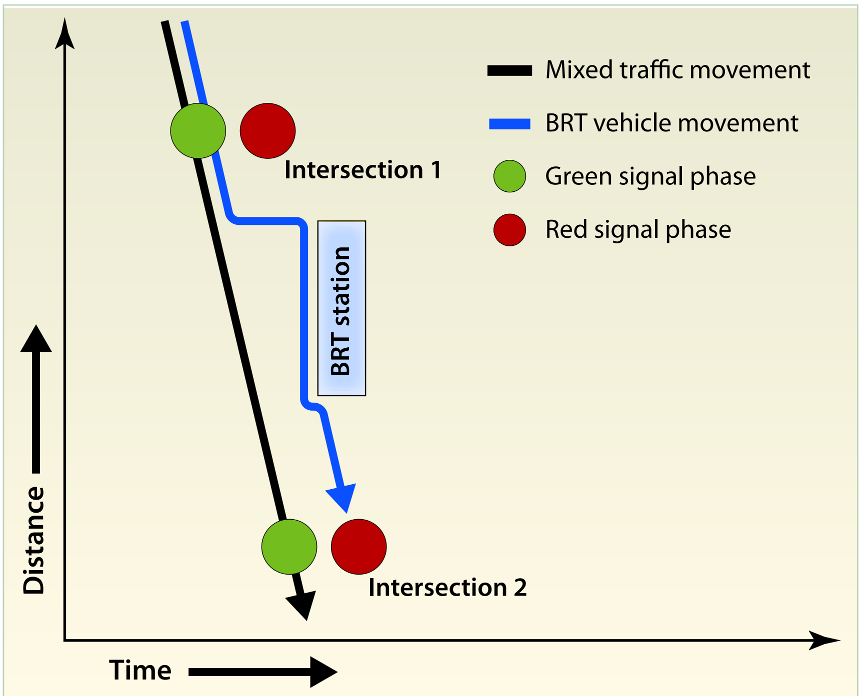
9.4.3.5 Optimising station location when intersections are close together

Sometimes, intersections are too close together in order to optimise the station location relative to the intersection. In such instances, an assessment has to be made in terms of how important the station location is for boarding and alighting passengers. If it is an important location, the time savings benefits for pedestrians of locating a station close to this destination must be weighed against the likelihood time lost within the BRT system due to interference between the station and the intersection. If there are no important destinations in that location, it is better not to locate a station there.

Mixed traffic vehicles will most likely be able to pass through the two intersections using a synchronised signalisation system. However, the same may not be true for BRT vehicles. Instead, the BRT vehicle will pass through the green phase at the first intersection and then stop at the station for passenger boarding and alighting. By the time the vehicle resumes movement towards the second intersection the signal phase may well have changed to red (Figure 9.48). Thus, this configuration may lead to considerable delay for public transport passengers.

Even for normal mixed traffic, having two intersections too close together will sometimes lead to problems. Vehicles queued at one intersection will back up to the point where vehicles are unable to clear the previous intersection during a green phase. Equation 9.12 defines the calculation for the distance at which this type of conflict may occur.

Fig. 9.48
While mixed traffic vehicles may benefit from a synchronised green phase between two intersections, BRT passengers may encounter the red phase at the second intersection.



Equation 9.12 Calculating the distance at which intersection conflicts occur

$$D12 < 3 * Max (Tg1, Tg2)$$

Where:

D12 = Distance between intersection 1 and intersection 2

Tg1 = Green signal time per phase cycle at intersection 1

Tg2 = Green signal time per phase cycle at intersection 2

A mixed traffic lane can generally handle 1,800 vehicles per hour. This quantity translates to two vehicles per second (3,600 seconds in an hour). When vehicles are stopped at a stop light, the average amount of space they take up is 6 metres; this space includes the vehicle and some space between vehicles. This average vehicle distance means that for each second of time, 3 metres of vehicle-equivalents can be moved through the intersection.

Box 9.4 provides a sample calculation of the required spacing between two intersections.

Box 9.4: Calculating vehicle queues between intersections

The following scenario is outlined in order to determine whether two intersections will result in free-flow operation or in congestion:

D12 = Distance between intersection 1 and intersection 2
= 100 metres

Tg 1 = Green phase time at intersection
= 40 seconds per phase

Tg 2 = Green phase time at intersection 2
= 30 seconds per phase

To determine if the distance between these intersections is sufficient, Equation 9.12 can be applied:

D12 < 3 * Max (Tg1, Tg2)

100 metres < 3 * 40 = 120 metres

Since 100 metres is less than the required 120 metres, there is not enough space between the intersections. It is therefore possible that vehicles queuing at the second light will back-up onto the first intersection. Since intersection 1 has a green phase of 40 seconds, some 20 vehicles will clear the intersection. As each vehicle on average consumes 6 metres of longitudinal space, 120 metres of vehicles will form a queue at the second intersection. If the intersection is only 100 metres away, then the queue will spill over into the first intersection and disrupt the functioning of the first traffic light.

9.4.4 Grade-separated stations

As has been noted earlier, grade-separating the busway at intersection locations brings with it many benefits from the perspective of travel time savings. A BRT tunnel or overpass will dramatically improve intersection capacity for both BRT vehicles and mixed traffic vehicles. A BRT tunnel will free-up surface space that can be utilised for mixed-traffic turning lanes.

However, grade-separation brings with it two complications. First, the infrastructure can be costly, depending on local circumstances. In many instances, the time savings to BRT passengers and to private vehicles will fully justify the added infrastructure costs, but limited capital resources will typically constrain infrastructure expenditures.

Second, grade-separation can limit the location of the stations. In most instances, grade-separation will imply placing the stations at a mid-block location, away from the tunnel or overpass. If a key destination is located at the intersection, this siting restriction will add walking time for customers travelling between the station and the key destination. The Quito Central Norte line uses grade separation quite effectively with tunnels whisking BRT vehicles through congested intersection locations. However, the tunnels also imply that at important destinations, such as the Plaza de las Américas (Plaza of the Americas), the closest station is a considerable distance away (Figure 9.49). Thus, from a customer perspective, the time savings from the grade-separation can be essentially lost due to the longer walk in accessing the intended destination.

As an alternative to this conflict between intersection efficiency and convenient station location, it is possible to place the station beneath the intersection. In this case, both the time savings of grade separation is gained as well as a convenient station location to key destinations. Many underground metro stations utilise station siting in this manner. The Metro Center station of the Washington Metro exits directly into the basement floors of commercial shops. In such cases, though, accessing ground-level shops and offices will require a grade transfer for customers, implying either stairs, escalators, and/or elevators. Likewise, both the

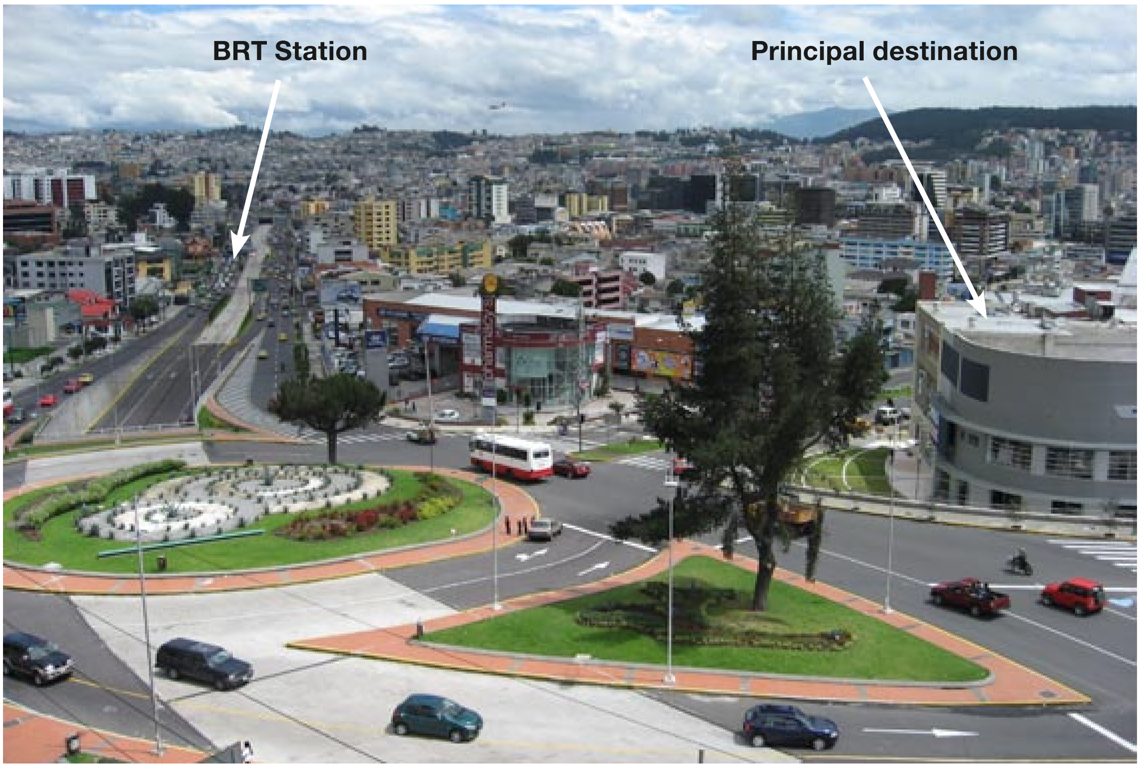


Fig. 9.49
In the case of Quito's Central Norte line, the presence of an BRT underpass has meant that the closest station to a key destination, the Plaza of Américas commercial centre, is several hundred metres away.
Photo by Lloyd Wright

Brisbane and Ottawa BRT systems site stations at the tunnel level. In Brisbane, the station is just before the tunnel and thus provides good customer access to local destinations (Figure 9.50). In Ottawa, the station connects directly to a commercial shopping centre (Figure 9.51). Further, in the case of Ottawa, the tunnel station nicely protects customers from the harsh winter temperatures.

Again, while grade separate on at intersection does increase initial construction costs, the time savings can justify the investment.

9.5 Roundabouts

"So many roads. So many detours. So many choices. So many mistakes."

—Sarah Jessica Parker, actress, 1965–

Intersections with roundabouts can create considerable uncertainty for the busway system. If the BRT vehicle must cross several lanes of mixed traffic within a heavily congested roundabout, the BRT vehicle may be hindered from proceeding. In turn, such unpredictability with congestion delays can create havoc for system controllers who are attempting to maintain frequent services and evenly-spaced distances between public transport vehicles.

However, there are some solutions to the difficulties posed by roundabouts. There are at least five distinct possibilities for accommodating BRT systems through a roundabout:

1. Mixed traffic operation;
2. Mixed traffic operation with signalised waiting areas;

Fig. 9.50 and 9.51
Placing stations just before a BRT tunnel (left photo, Brisbane) or even within the tunnel (right photo, Ottawa) helps customers with comfortable access to local destinations.
Left photo courtesy of Queensland Transport
Right photo by Lloyd Wright

Fig. 9.52
Quito's Ecovía line cuts directly through a roundabout.
Photo by Lloyd Wright

3. Exclusive lane along inside of roundabout;
4. Exclusive busway through the middle of the roundabout;
5. Grade separation.

If mixed traffic and BRT system volumes are not particularly heavy, then simply allowing the BRT vehicles to enter mixed traffic may be an effective and simple solution. In such cases, the BRT vehicle will leave the dedicated busway upon entering the roundabout, which may be either controlled through a traffic signal or left to operate on a yield priority basis.

Section 9.3.4 above has already discussed the possibility of converting a standard intersection to a roundabout with signalised control and BRT waiting areas. This option can be appropriate when a standard intersection has reached its saturation point and a variety of turning options for private vehicles must be accommodated.

In cases where BRT and mixed traffic volumes dictate that some priority must be retained for the BRT vehicles, then making the inside lanes of the roundabout exclusive to BRT can be an effective option. In this case, the BRT vehicles can access the exclusive roundabout lanes either by crossing mixed traffic lanes or by being given priority signalisation. Likewise, to exit the roundabout and re-enter the principal busway the BRT vehicle must cross mixed traffic lanes. As with the entry to the roundabout, the BRT vehicle can either manoeuvre across mixed traffic to exit the roundabout or another set of traffic signals can be used to facilitate the exit.

Depending on the physical contents of the roundabout, a dedicated lane could be constructed through the centre of the roundabout. In this case, the busway is built straight through the roundabout while mixed traffic continues to circulate around it. Quito's Ecovía line provides an example of this technique (Figure 9.52). Likewise, the Cali (Colombia) system makes use of this approach (Figure 9.53). The ability to construct a dedicated lane through the centre of the roundabout will only be feasible when the centre area of the roundabout does not host a fountain, sculpture, or other permanent piece

Fig. 9.53
In Cali (Colombia), the busway also passes through the centre of the roundabout area.
Photo courtesy of Metrocali

of urban infrastructure. The construction of the BRT system should not involve the loss of any items of cultural identity. In this design, a traffic signal controls enter to and from the roundabout.

Finally, the most elaborate solution is to construct a busway underpass that goes below the roundabout, and thus avoids all conflicts with mixed traffic. Quito has achieved great success with its "Villa Flor" station that goes beneath the heavily-trafficked roundabout on Maldonado Avenue. Likewise, a series of underpasses near Plaza America en Quito avoids much potential congestion for the city's Central Norte line (Figure 9.54). As noted previously, while grade separation is potentially the most effective solution in terms of intersection efficiency, its applicability depends on cost and locational factors. In some circumstances, underpasses can be quite expensive to construct, although the expected time savings for both BRT and mixed traffic vehicles can justify such costs. Also, an underpass can complicate station location, especially if there are key destinations near the intersection. Of course, as in the case of Quito's Villa Flor roundabout, it is possible to locate the station within the underpass itself, which gives customers good access to destinations near the roundabout.

Fig. 9.54
Quito's Central Norte line uses a series of underpasses to avoid a roundabout near Plaza Américas.
Photo by Lloyd Wright

9.6 Traffic signal priority

"A common mistake that people make when trying to design something completely foolproof is to underestimate the ingenuity of complete fools."

—Douglas Adams, novelist, 1952–2001

Traffic signal priority for BRT vehicles can take one of two forms:

1. Passive signal priority;
2. Active signal priority.

Passive signal priority is the adjustment of normal traffic signals to give priority to a corridor with a BRT system over a corridor without one, and to give priority to the BRT system over mixed traffic within that corridor. Active signal priority tends to be activated by electronic equipment that detects the arrival of a BRT vehicle at an intersection and adjusts the traffic signal accordingly.

9.6.1 Passive signal priority

Passive signal priority should always be a basic first step in giving a BRT system traffic signal priority in a given corridor. Signal priority is quite complementary to the signal phase simplification discussed earlier, and thus the two techniques can be considered jointly for implementation.

One of the most basic measures within passive signal priority is to give BRT corridors preference over cross streets that do not have public transport services. This prioritisation can be achieved by extending the green time for the BRT corridor over the cross street. This action will improve the travel speeds of all the traffic (both bus and mixed traffic) on the BRT corridor at the expense of all the traffic on the non-BRT corridor.

The next step is generally to see if the signal phases on the BRT corridor can be shortened. Because BRT vehicles are less frequent than mixed traffic vehicles, they are more adversely impacted than mixed traffic by long signal phases. The actual optimal signal phase will depend on both the flow of BRT vehicles and the flow of mixed traffic.

It is not unusual for total cycle time on a BRT corridor to be as low as 60 to 90 seconds, rising to as high as 120 seconds or longer only at major intersections or during peak hours and mainly to extend the green time within the BRT corridor. On a BRT corridor, the red time faced by the BRT system should be as close as possible to 50 percent of the total signal cycle. It is typical for the BRT green time to be 30 seconds in a 60 second cycle, or 40 to 60 seconds on a 120 second cycle.

In systems like Kunming where the station is adjacent to the intersection and the signal phase is 180 seconds, bus queuing problems are typical even at fairly low capacity. Likewise, delays occur in Kunming due pedestrians crossing against the light, which leads to serious safety problems.

Synchronisation of green signal phases between intersections is not common with BRT systems. Since BRT boarding and alighting times can be somewhat irregular, determining the signal timing between intersections is quite difficult. If BRT vehicle speeds are reasonably predictable, and intersections are less than 1.6 kilometres apart, it may be possible to coordinate traffic lights in a BRT corridor. This practice is used in Ottawa (Levinson et al., 2003b).

9.6.2 Active signal priority

Active, or real time priority techniques, change the actual traffic signal phasing when a BRT vehicle is observed to be approaching the intersection (Figure 9.55). At an even higher level of sophistication, the priority phasing can be based on observed traffic levels for both the BRT vehicles and the general traffic. The importance of traffic signal priority on BRT vehicle speeds tends to be greatest in systems with fairly low bus volumes, particularly with bus headways longer than five minutes. When BRT vehicle headways are less than 2.5 minutes, it is generally difficult to implement active signal priority at all. If signal phasing was attempted in such high frequency circumstances, the non-BRT traffic direction would essentially be in a state of a permanent red phase, although applying the signal priority to alternating phases would still be possible.

Fig. 9.55
Active signal priority for BRT and restricted turning movements for mixed traffic vehicles can do much to improve public transport travel times.
Photo by Lloyd Wright

In developing countries, where volumes on BRT corridors tend to be high, intersections relatively few and far between, and traffic light systems weak and badly maintained, traffic signal priority measures for BRT systems have been less used than in developed countries with frequent intersections and longer headways. However, even with high bus frequencies, measures such as green phase extension and red phase shortening can be used, particularly at less important cross streets, yielding benefits on the order of a 4 percent to 10 percent reduction in traffic signal delay. While this savings is not as significant as some other priority measures, it can be an important contributing factor to efficiency gains.

In the US and Europe, where intersections are frequent and lead times between buses often five minutes or longer, signal priority measures may be a more important measure for increasing bus or tram speeds. In such instances, signal priority may reduce signal delay by between 10 percent and 20 percent. In this context, it is often easier to give buses signal priority at intersections without major disruption of mixed traffic flows.

Because most BRT systems to date have been developed in developing countries with high bus frequencies and relatively few intersections, most of the famous BRT systems have relied primarily on turning restrictions to increase intersection efficiency and have not relied heavily on sophisticated real time signalling systems. With an exclusive bus lane and an optimised station design, the additional benefits for BRT vehicles resulting from high technology signalling systems may be small relative to the cost of the signalling equipment. However, as vehicle detection, signalling equipment, and priority software have become increasingly common, the costs are becoming increasingly affordable.

For traffic systems where flows are quite irregular, real time control systems which weight signal times to observed traffic levels can yield benefits. In such real time systems, phase changing is usually based on a trade-off between the benefits and costs faced by the green and red approaches. A special weighting can be given to BRT vehicles or to the BRT corridor. For the general principle of shortening red times, a fully actuated system based on total vehicle movements which also includes BRT vehicles is probably more important than BRT-specific detection.

The normal vehicle identification mechanism is to have a transponder detect the BRT vehicle prior to its arrival at the stop line. If the BRT vehicle is detected during the green phase, and the green phase is nearing the yellow phase, the green phase is extended. If the detection occurs during the red or the yellow interval, the green time is recalled in advance of normal time. Some general guidelines for applying phase extension or phase shortening include:

- The minimum side street green time is set based on the amount of time pedestrians need to cross the road;
- The amount of green signal extension or advance should be up to a specific set maximum;
- The BRT corridor green is not generally both advanced and extended in the same cycle.

The green times are likely to be most easily extended at intersections with light cross traffic.

A possible important use for vehicle actuated signals is for special turning movements onto or off of the BRT corridor. If an intersection has a small number of BRT routes that need to turn left (or right in a British-style configuration), a special left turn phase can be added to the cycle upon the detection of the BRT vehicle. When the turning movement does not have a special lane, a TAG, GPS or similar individual bus detection technique may be needed. Benefits on these kinds of actuated systems for special turning movements can save up to 30 percent of signal delay not only for the BRT system but also for general traffic.

Real time activation of signals can also be used on specific critical bottlenecks along a BRT corridor. For example, sometimes a BRT system must pass through a narrow stretch of road that is impossible to widen. Such areas may include bridges, tunnels, city gates, or flyovers. Usually the heaviest congestion occurs not on the critical link but just before it, forming a large queue just to enter onto the bottleneck point.

When the facility itself is not congested, only the approach to the facility, a traffic signal is generally not needed, and it may be better to end the exclusive busway just a short distance before the bottleneck. The distance should be sufficient only to allow a convenient distance for merging (40 to 80 metres). This curtailment of the busway will allow BRT buses to pass through most of the congestion point without provoking any reduction of mixed traffic capacity at the critical section (Figure 9.56).

If the critical link is an approach to signalised intersection, the BRT lane should finish at a given distance. Equation 9.13 provides the calculation for determining the optimum distance for terminating the exclusivity of the busway.

Equation 9.13 Calculating the optimum distance for terminating the busway

$$L \text{ (metres)} = \sim 3 * Tv \text{ (seconds)}$$

Where:

Tv = Green phase time for the BRT approach

This calculation, however, no longer works if the facility itself also becomes congested. If there is a risk that the bottleneck facility itself may become congested, a special signal should

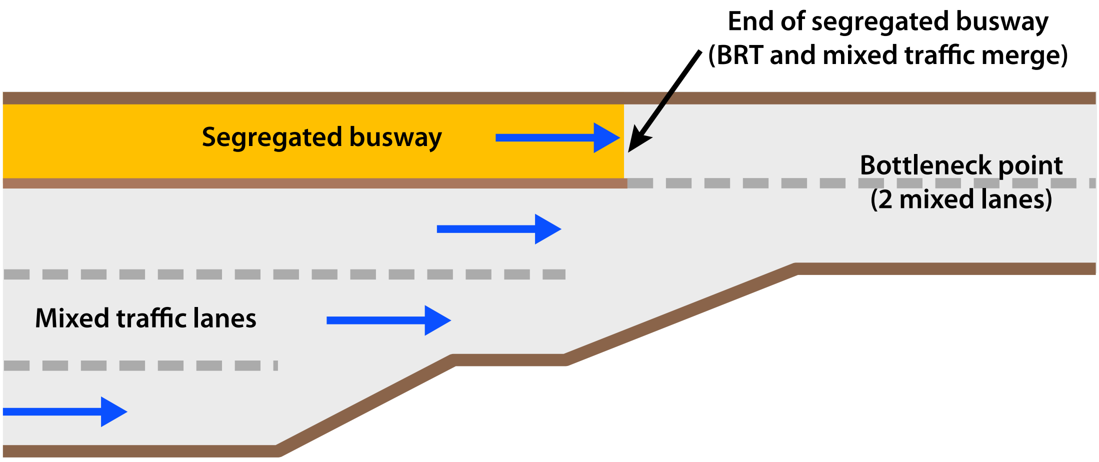


Fig. 9.56
In the case of a severe bottleneck point, it may be best to terminate the exclusivity of the busway prior to reaching the bottleneck.

be used. This signal would generally flash yellow until the point where traffic detectors note that the critical link has itself become congested. At that point, the signal would be activated, and a red signal would be given to mixed traffic until the bottleneck clears (Figure 9.57). The selective use of such a traffic signal will help to avoid congestion inside the busway. Instead the delay is transferred to the mixed traffic in the previous link, resulting in improved velocity for BRT vehicles at the critical link. For tunnels, this approach has the extra advantage of avoiding idling vehicles within heavily polluted conditions.

The example given in Figure 9.57 essentially acts as a queue-jumping mechanism in which the BRT vehicles are given an advantage through a bottleneck point.

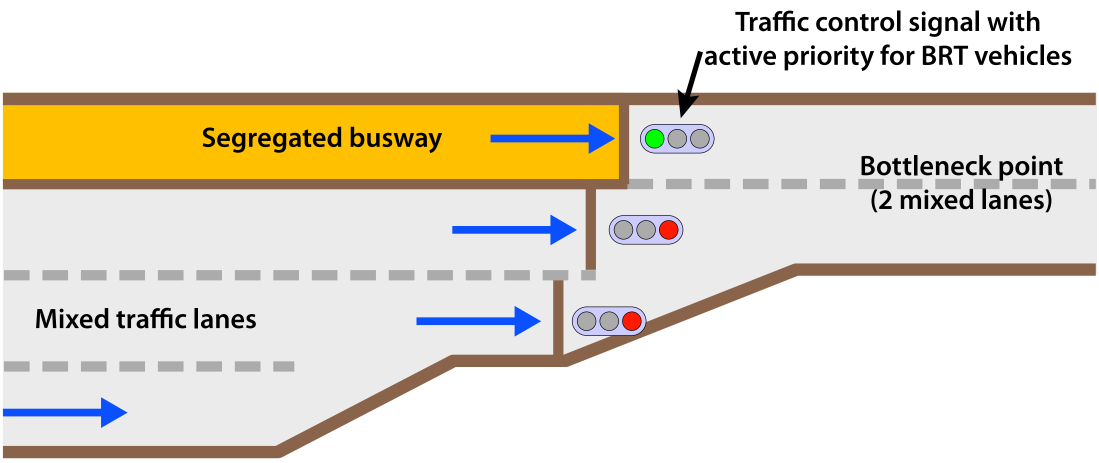


Fig. 9.57
If the bottleneck area itself is congested, then traffic signal control, with active priority for BRT vehicles, may be an appropriate solution.

10. Customer service

"Consumers are statistics. Customers are people."

—Stanley Marcus, retail entrepreneur, 1905–2002

Unlike many existing bus services in developing cities, BRT places the needs of the customer at the centre of the system's design and implementation criteria. The quality of customer service is directly related to customer satisfaction, which will ultimately determine customer usage and long-term financial sustainability.

Unfortunately, unclear maps and schedules, unclean and ill-maintained vehicles, and uncomfortable rides have all too frequently been the norm for those who utilise public transport in developing cities. Public transport and paratransit operators sometimes pay scant attention to customer service, assuming instead that their market is comprised of captive customers, who have no other option but to use their services. Such a predilection, though, can lead to a downward spiral, in which poor service pushes more commuters towards two-, three-, and four-wheeled motorised alternatives. In turn, the reduced ridership limits public transport revenues and further diminishes the quality of service, which in turn leads to a further erosion of the passenger base. The impacts of poor customer service may not be immediately evident when the majority of users are "captive" riders who indeed have few other transport options. However, in the medium and long term, as income increases, these captive riders will become discretionary riders. The discretionary riders are quite likely switch to individual motorised transport as soon as it becomes financially feasible to do so.

Customer service is fundamental at each level of operation. Are drivers courteous, professional and well presented? Are the stations and the vehicles clean, safe and secure? Is the morning commute a pleasant and relaxing experience or is it a hazardous and unfortunate trauma that must be endured? Are there opportunities for people to complain, receive information, and be heard? Individually, factors such as driver behaviour, signage, and seat comfort may appear to be trivial measures, but their combined effect can be a significant determinant in a public transport service's long-term viability.

While these design and service features can make dramatic improvements in system effectiveness and customer satisfaction, each is relatively low-cost to implement and relatively low-tech in nature. Thus, another lesson from BRT is that simple, ingenious, low-technology solutions are often of much greater value than more complex and costly alternatives. Customers probably do not care about the type of engine propulsion technology, but they do care greatly about the simple customer service features that directly affect journey comfort, convenience and safety. Despite this rather obvious observation, too many public transport developers devote their entire attention to the vehicle and engineering aspects of system design and forget about the customer service aspects.

The contents of this chapter include:

10.1 Customer information

"Well done is better than well said."

—Benjamin Franklin, author, politician, and scientist, 1706–1790

10.1.1 System maps

Historically, the ad hoc nature of para-transit systems in much of the developing world has followed informal and uncontrolled routings that require a seasoned system insider to fully understand and utilise. Many such systems are relatively incomprehensible to the customer. The lack of system clarity is especially a formidable barrier to potential new users (*e.g.,* visitors) and those residents with only occasional transport needs.

In South Africa, customers must become familiar with a range of hand signals that indicate to the driver the destination of the customer. If the customers hand signal matches the intended route of the driver, then the vehicle may stop and pick-up the customer. Subtle differences in the hand signal can mean a very different destination. Further, the hand signals vary by each city, so a person must learn a new set of hand signals for each different city and/or sector of a city. Clearly, this type of system creates a tremendous barrier to use. In order to help customers, the City of Johannesburg actually created a directory of hand signals (Figure 10.1). However, it would take a very dedicated user to learn all the signals.

In reality, better maps and signage is not a terribly difficult task. With just a bit of effort and imagination, cities can create visual cues that are highly customer friendly. For example, the Metrovía system in Guayaquil emulates the better metro systems of the world by providing clear and colourful system maps (Figures 10.2).

A good test of a system's user-friendliness is to determine whether a visitor who does not speak the local language can understand the system within two minutes of looking at a map and information display. It is possible to achieve this level of simplicity in conveying the system's operation, but, unfortunately, most public transport systems today do not even make the attempt to do so. By contrast, systems such as the Beijing BRT system, actually provide system information in multiple languages.

Unlike the well-designed and colour-coded maps accompanying many rail-based systems, maps for conventional bus systems are often quite confusing. While metros tend to use colourful "spider" maps to designate routes, most conventional bus systems use a complex web of mono-coloured lines and numbers (Figures 10.3). However, higher-quality bus

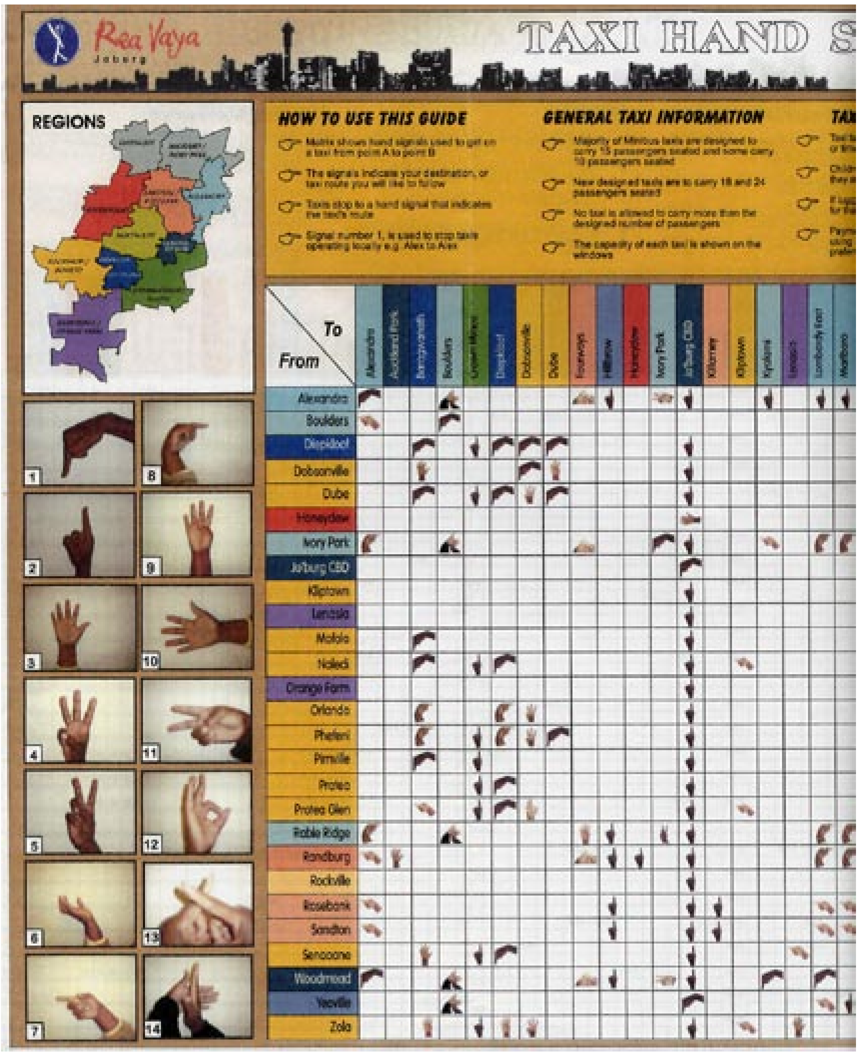


Fig. 10.1
A portion of a Johannesburg directory that instructs how customers can signal their intended destinations to minibus taxi drivers.
Image courtesy of the City of Johannesburg

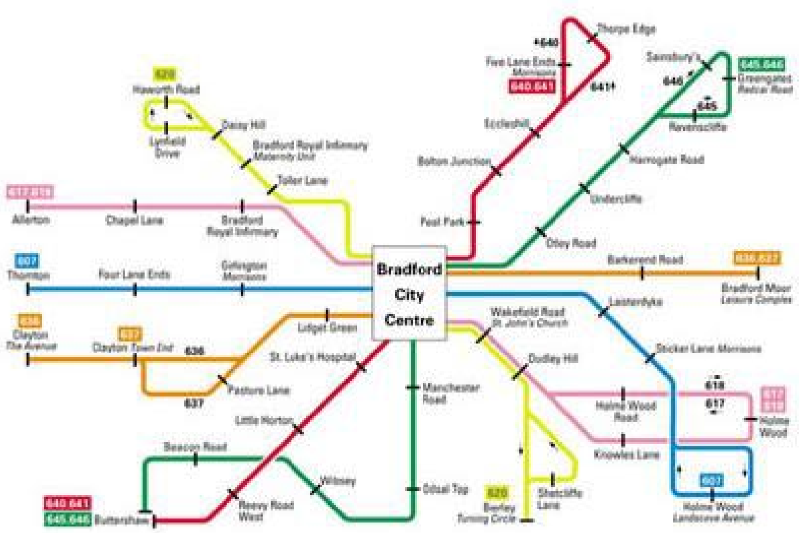
Fig. 10.2
System map for the Metrovía system in Guayaquil.
Photo by Lloyd Wright

Fig. 10.3
This conventional map of bus routes in central London is quite difficult to read and understand.
Image courtesy of Transport for London (TfL)

Fig. 10.4
This "spider map" as used in Bradford (UK) provides a user-friendly view that allows customers to quickly understand how the system functions.

systems are increasingly making use of spider maps to better convey information to customers (Figure 10.4). The idea behind a spider map is to give each route its own colour-coded identity. The entire route is evident along with all major stations. The spider map from Bradford (UK) is part of a marketing strategy to re-brand the bus network as an "Overground" system. The word "Overground" is borrowed from the name of the London metro system which is known as the "Underground". Thus, the spider map in Bradford helps impart the idea that the bus network is a quality mass transit system.

The differentiation of routes can be communicated through a variety of mechanisms including colours, numbers, and destination names. Colour-coding schemes are effective in allowing customers to readily differentiate between multiple routes. Also, colour-coding can be reflected both in the system route maps and on the vehicle itself. For instance, a coloured sign-board on the front of the vehicle can designate the routing direction. The sign-board is easily removable in order to allow maximum flexibility in using the same vehicle on multiple corridors, depending on changes in customer demand patterns. Generally, customers can discern colours faster they can identify route numbers or worded destinations. However, in reality, route numbers, colour-coding, and destination labels can actually be used together to maximise customer recognition. Of course, care must be exercised so that too much visual complexity does not result. The best design is one that clearly communicates routes and destinations without undue complexity.



Quito's "Trolé" line operates a somewhat complex routing system in which five different sub-routes are utilised along a single corridor. Through this system, Quito is able to provide the most frequent services to the central routes with the highest customer demand. The provision of such sub-routes does much to improve the technical efficiency of the system. However, customers are largely on their own in terms of attempting to distinguish the route associated with the approaching vehicle. Since all vehicle routes stop at the same single platform sub-stop, customers must identify the appropriate routes based on a number card on the front of the vehicle. There are no platform announcements and there are no visual displays to indicate which sub-route is associated with the arriving vehicle. Unfortunately, the station infrastructure prohibits a clean view of the number card on the vehicle front (Figure 10.5). Thus, customers have just a blurred view for a split second of the sub-route number. Further, since the audio announcement within the vehicle is often not functioning or the sound is such poor quality that it is unintelligible, customers on-board may have no idea what sub-route they are using. This sort of poor communication ultimately affects system efficiency regarding customer transfers and bunching at transfer stations. In turn, customer satisfaction with the system is jeopardised through such difficulties.

Time-based route maps are a simple and yet highly useful customer service feature. With a

Fig. 10.5
With no announcements or electronic display, customers on the Quito Trolé only have a brief, sight-line impaired view of the route number for the vehicle approaching the station.
Photo by Lloyd Wright

Fig. 10.6
This time-based route map in Nagoya (Japan) allows customers to gauge the amount of time required to travel to their destination.
Photo by Lloyd Wright

time-based route map, the average amount of time required to travel between points is incorporated into the map (Figure 10.6). Customers can thus quickly gauge their expected journey time.

The completeness of a particular map can also affect system usability. In some systems, such as Curitiba, only the map for one particular corridor is displayed at stations and within the vehicles. This limitation implies that persons only have a good working knowledge of their most frequently utilised corridors. Therefore, people may not be able to use the system as adeptly for occasional trips. Moreover, the lack of an overall map means that customers cannot easily plot the most efficient routing for linked journeys with multiple destinations (*e.g.,* work to shopping to school to doctor, etc.). The absence of a complete system map is also quite disadvantageous for visitors and occasional public transport users. Thus, it is recommended that a complete system map be present at stations and inside vehicles. Of course, there are cost issues associated with providing quality maps, but in comparison to other aspects of system development (vehicles, bus ways, stations, etc.) the cost is relatively small.

Effective placement of maps in vehicles and stations is also a determining factor in the system's user-friendliness. In Bogotá, updated maps are only available inside the station and within vehicles. However, some customers would like to visualise the system and route before paying and entering the system. Thus, it would be best to also have a system map outside the station entry point. The idea is to make the system as simple and as inviting as possible to the customer. A major deterrent to public transport usage is the fact that many potential customers simply do not understand how the system works. A route map outside the station may also be an opportunity to visually engage persons who normally do not utilise the system. Thus, a visually-stimulating route map can actually be part of a marketing strategy to inform non-users, such as passing motorists, of the system's potential relevance to their daily travel patterns.

The provision of neighbourhood maps of the local area can be quite useful to customers. In many case, a person may be proceeding to an address near a particular station. A local area map can then direct the person to their destination from the station (Figure 10.7).

As the system grows, the updating of maps can become a costly exercise. Thus, careful consideration of how future map additions will be handled should be done at the outset. This planning exercise may include a cost comparison between printing and distributing new maps with each new corridor or merely adding an overlay to the existing map.

Fig. 10.7
A local area map at this station of the Bangkok MRTA system helps customers find their way to their final destination.
Photo by Lloyd Wright

10.1.2 Signage

In addition to system maps, the various signage in and around stations as well as within the vehicles are key in helping customers readily understand the system. Examples of the types of signage likely to be needed include:

- Instructions for using fare collection machines or vending booths;
- Identification of station entry and exit points (Figure 10.8);
- Standing location within the station for particular routes (if multiple stopping bays);
- Directions for making transfers at terminals and intermediate transfer stations;
- Actions required in the event of emergencies (instructions for call boxes, fire suppressing equipment, etc.) (Figure 10.9);
- Identification of locations within the vehicle for persons with special needs (physically disabled, elderly, parents with child, passengers with bicycles, etc.);
- Directions to amenity facilities (*e.g.,* bicycle parking facilities, restrooms, etc.).

Fig. 10.8 and 10.9
Signage in stations in Quito (left photo) and Ottawa (right photo) provide clear guidance to customers.
Photos by Lloyd Wright

Fig. 10.10
As this example from Bangkok shows, instructions on the platform floor can be useful in facilitating efficient customer movements.
Photo by Lloyd Wright

The fare collection process is another area of potential customer confusion that may hinder the system's usability. While regular users and captive users will make efforts to understand pricing and purchase options, other customer groups can view the fare system as another complication, inhibiting usage. Clear and simple instructions are essential. Ideally, the design should be clear enough that a person who does not speak the local language can readily understand fare amounts and payment methods.

Transfer points and vehicle stopping locations are also potentially confusing for the customer. Confusion can be particularly acute during peak periods when crowds, noise, and distractions are at an intense level. Such signage should be sufficiently sized and eye-catching in order to effectively lead customers to the right location. System designers should walk through the likely steps of a prospective customer in order to place the signage at the correct point. For example, signage directing customers to transfer points may be best placed directly across from the exit points of alighting customers.

Certain vehicles areas are typically designated for customers with special needs, such as those with physical disabilities, the elderly, pregnant women and young children. These areas can be readily identified with the use of appropriate signage as well as colour-coding. The colour-coding may entail using distinctly coloured seating in such areas.

10.1.3 Advertising

Signage and visual displays may not just be present to inform customers on the public transport system. Advertising displays may be part of a strategy to secure needed income for the system.

However, while advertising in many cases performs an important revenue role, there may be instances when it becomes a detriment to the effective transmission of other forms of information. An overabundance of visual displays can hamper effective communication. If too much signage and/or advertising is present, a point of diminishing returns can be crossed. Too much signage can be visually distracting and may prevent customers from absorbing vital information. "Visual clutter" is particularly problematic when systems post extensive advertisements. In some cases, as practised with Japanese metro systems, the advertising actually protrudes into customer space and diminishes overall comfort as well as creating claustrophobic environment (Figure 10.11).

Fig. 10.11
Visual clutter from hanging advertisements in Japanese rail systems can hamper the customer's ability to see other information, such as system maps, as well as reduce inside and outside visibility.
Photo by Lloyd Wright

Advertising on the sides of vehicles can be an eye-catching opportunity for firms (Figures 10.12 and 10.13). However, the painting of the vehicles can restrict visibility for those inside the vehicle, which can create customer stress for those trying to identify the station name. Additionally, substituting a recognisable system name and colours with an advertising message can reduce the branding potential associated with a quickly identifiable vehicle.

Some cities have recognised that the space on the outside of the vehicle can represent a valuable property for advertising messages. Both the size of the vehicle sides and the eye-catching nature of a large message moving through a city centre make such advertising a potentially lucrative revenue source. However, the decision to replace the system's brand and logo with a commercial message is not one to be taken lightly. By forfeiting this space to commercial uses, an opportunity to create a highly-recognisable marketing identity for the system can be lost. Even if the system's logo appears in conjunction with the commercial message, its impact is substantially reduced due to the sharing of this visual space.

Further, the painted image can diminish visibility for passengers inside the vehicle. Generally, the commercial message is painted onto the vehicle in a pixelised manner in which an overall image is formed from many tiny spots of paint. The translucent nature of the paints and the pixelised nature of the image does allow passengers to see outside. However, the quality of the view is reduced. The ability to recognise outside landmarks can be important for passengers seeking to identify the correct stop for getting off the vehicle. Additionally, viewing the outside landscape is one of the factors that affect passenger enjoyment.

Fig. 10.12 and 10.13
Advertising painted onto the outside of the vehicle can be a useful in generating system income. However, the advertising will tend to reduce the system's own marketing and branding efforts as well as diminish visibility for passengers inside the vehicle.
Left photo (Bangkok Skytrain) by Lloyd Wright
Right photo by Eric Strauss of Orlando LYNX

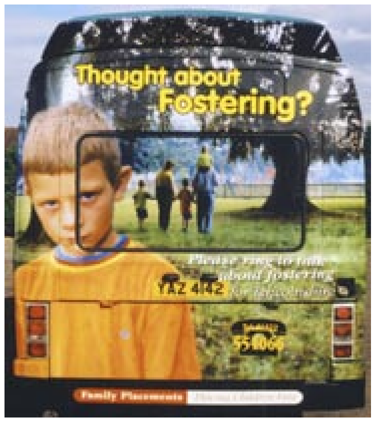


Fig. 10.14 and 10.15
Public service announcements such as air-quality information posted in the Montreal subway and a foster-care message in the UK do much to serve public awareness.
Left photo by Lloyd Wright
Right photo courtesy of Adbus

Advertisements should thus be used discretely in order to not become too obtrusive towards other information. Quite often, reducing the quantity of advertisements can actually increase revenues. This result occurs due to the relative scarcity of the supply. As the space allowed for advertising becomes restricted, the bid price for the space becomes more valuable.

10.1.4 Public service messages

In addition to commercial messages, a public transport system may also wish to permit "public service announcements" (PSAs) within the system. While PSAs do not bring in any advertising revenue, their presence does serve an important public service. PSAs provide information on a variety of causes, including:

- Access to public services (health, education, employment, etc.);
- Awareness campaigns on key topics such as HIV/AIDs, child services (Figure 10.14), security and safety, the environment (Figure 10.15), voting, etc.
- Behaviour change in terms of smoking, litter disposal, abuse, etc.

Thus, a public transport system can be seen as a tool to achieve a variety of public outreach objectives and add even further value to the life of its customers. A public transport system may be one of the few places that a person might be exposed to such messages. PSAs demonstrate that a system recognises its role and responsibilities in serving the greater needs of the community. A public transport system should be viewed not only as a transit service moving persons from point A to point B, but also as a trusted member of the community.

10.1.5 Visual and voice information systems

Traditional signage is just one way of conveying information to customers. Visual displays with real-time information are increasingly being used to relay a variety of messages. Such devices can display the following types of information:

- Next station stop (display inside bus);

Fig. 10.16
An information display in the interior of a TransMilenio vehicle in Bogotá.
Photo by Dario Hidalgo

Fig. 10.17
Real-time information display along a platform of the Brisbane busway system.
Photo courtesy of Queensland Transport

- Estimated arrival time of next vehicle (display on station platform);
- Special advisories, such as delays, construction work, new corridors, etc.
- Customer service announcements such as information on fare discounts.

Real-time information displays that inform passengers when the next bus is due can be particularly effective at reducing "waiting anxiety", which often affects passengers who are not sure when, or if, a public transport vehicle is coming (Figures 10.16 and 10.17). This feature allows customers to undertake other value adding activities to make best use of the time, rather than waiting nervously and paying close attention to the horizon. Such displays can reduce the customer's perceived waiting time substantially.

Voice communications can also be a useful mechanism to transmit essential information. For instance, announcing the next station allows customers to focus on other activities (such as reading, talking with friends, etc.). Otherwise, customers usually tend to look up at displays or station names frequently. Forcing the customer to be familiar with the local environment can add stress to the journey, especially for visitors and occasional public transport users. Further, during crowded peak-hour conditions, obtaining a clear view of outside signage can be difficult.

Voice messages can be transmitted by way of the vehicle driver or by using recordings. Typically, recordings are recommended as they can be clearer and more consistent. Also, recorded messages can employ digital technology rather than analogue technology. Digital voice messages are more readily understood than local analogue messages. Furthermore, each driver will have his or her own accent and it may not be understood by all. Employing pre-recorded digital messages with automatic activation at certain points in the journey will assure a uniform and reliable information source. Additionally, digital messages will allow the driver to better concentrate on safety and other aspects of customer service. In some circumstances, it may be practical to deliver brief destination messages in more than one language.

Even with a digital recording that provides vehicle location, there will be instances when a message from the driver will be appropriate. If there is an incident or system delay, the driver can relay that information to the passengers. It is always best to keep customers fully informed of any situation to the extent possible. Understanding the reason for a delay (*e.g.,* traffic accident, weather conditions, etc.) will tend to calm passenger anxiety. Driver messages are also obviously quite important during any emergency situation.

10.1.6 Customer interaction

Effective customer relations should not be a one-way flow of information. The best source of system evaluation and feedback is likely to emanate from actual users. In many cases, customers will identify problems and potential solutions long before system managers and designers. Unfortunately, this knowledge resource is often ignored.

Encouraging customer input is not an easy process. The dispersed and decentralised nature of customers can make a meaningful dialogue difficult. While virtually every customer will have a defined opinion on the public transport service, few will make the effort to provide feedback, especially if the system managers do not provide an easy opportunity to do so.

Some of the most common mechanisms to obtain customer inputs include:

- Call centre;
- Email contacts and web site information;
- Direct mail;
- Physical suggestion box;
- Customer service desk;
- User surveys;
- Ombudsperson and/or user representation in the board of directors.

Effective customer interaction should involve both "passive" and "active" mechanisms. Sole reliance upon passive measures, such as a call centre and an email address, means that only customers with a strongly-felt issue will provide inputs. Such self-selecting inputs may not be wholly representative of overall customer opinion. By contrast, a user survey, while more costly, is perhaps the most thorough mechanism to gather customer opinions and suggestions.

10.1.6.1 Call centres

Providing a telephone service for customer enquiries is one of the most basic features of customer interactions. Call centres will likely handle a range of requests, including basic system information, complaints, and recommendations. These different types of requests can be handled through a single number or through individual numbers for different request types. However, as the number of telephone numbers increase, there can be increased confusion amongst users. A single telephone number for multiple customer enquiries can be easier to gain marketing awareness of the telephone number. However, a single enquiry line necessitates that all call centre operators are sufficiently knowledgeable to handle a wide range of requests. The number of available operators must be carefully selected to avoid customer waits. Ideally, an operator will pick-up immediately or within a few minutes of the customer's call.

Call centres can either be operated directly by the public transport operators, or the centres can be contracted to a specialised firm. In the case of a contracted firm, quality control oversight will likely be required to ensure that a useful service is being delivered. All the information collected by the call centre should be documented and analysed by the public transport agency. A regular report on customer enquiries can be a useful evaluation tool to be shared with staff, board members, and the public.

The rapidly increasing use of mobile telephones also offers another avenue of customer inputs through SMS (Short Message Service) texting. A number should thus also be provided to permit comments and suggestions through texting.

10.1.6.2 Email contacts and web site information

Provisions for web-based inputs should also be made available. A "contact-us" icon along with basic contact details (telephone and email contact information) should be prominently noted on the home page of the system's web site.

Information on the web site can help to provide customers with basic questions about system operating hours, route structure, tariffs and payment methods, and system facts and figures. Thus, the contents of the web site can do much to answer enquiries without the need of a customer directly contacting the public transoprt agency. Common enquiries handled in this manner can save staff resources.

Fig. 10.18
The feedback form provided on the TransMilenio web site.

The web site can also be used to encourage and structure feedback. An on-line form to handle complaints, suggestions, and comments can ease the feedback process. However, the nature of the form should not be too restrictive in terms of acquiring a broad range of customer inputs. Figure 10.18 provides an example of the feedback form utilised by TransMilenio in Bogotá.

Even with such automated data collection, agency response should be as personalised as possible. Each input should be carefully read and responded to in a timely fashion. System administrators may even wish to give gifts or special recognition to customers who provide highly useful suggestions for improving the system. A public transport pass (for a day or a week) or system merchandise can be effective incentives for rewarding useful inputs.

As with telephone inputs, it is advisable to organize all data received in order to provide a historical series of comments and concerns. In this way, managers can follow up on trends, and identify the main concerns over time. It is likely that the number of communications received will be small compared to the large number of passengers, but the fact that someone takes time to make a phone call, write an e-message, or fill out a complaint means that the message is of interest to system developers and managers.

10.1.6.3 Customer service desks

Web services, emails, telephone, and texting are fine options for some customers. However, in many developing-nation cities, not all customers will have access to such options. Thus, more direct and conventional options should also exist to encourage customer interactions.

The provision of a customer service desk or booth is quite important in terms of giving all customers access to a system representative (Figures 10.19). Further, such centres can help put a more human face onto customer interactions. Many customers simply prefer speaking face-to-face with a real person in order to answers to their most pressing questions.

Customer service centres are frequently located at terminal sites, especially given the relative availability of space over smaller stations. Terminals and large station locations also frequently provide a maximum throughput of customers in order to ensure that the customer desk is adequately utilised. However, off system sites are also a possibility. Customer service centres in commercial centres, public buildings, and public plazas can also be quite appropriate.

Fig. 10.19
A customer information service centre for the Ottawa BRT system. This office is located within a major commercial centre near a downtown station.
Photo by Lloyd Wright

Like call centres, staff working at the customer centres must be fully trained to handle a wide variety of requests and inputs. Staff should make note of all enquiries given, so that these comments and trends are properly categorised and passed along for managerial analysis. Service centres may also provide suggestion boxes and forms for customers who wish to provide written comments.

10.1.6.4 Survey forms

As noted, customer interactions should not just be passive in nature. Instead, system operators should actively seek out customer opinions and inputs on a regular basis. Customer surveys provide a structured mechanism to regularly evaluate customer satisfaction and customer concerns.

The structure of the survey should be professionally designed. Great care must be taken to ensure that biases are not introduced into the survey questions. Thought should be given to the long-term applicability of questions so that the same survey structure can record a time-series comparison of customer inputs. The length of a survey must be carefully determined. Customers within the system are likely to be unwilling to give anything more than a few minutes to a questionnaire.

Surveys for public transport are typically administered to customers within the system. Surveys can be applied to either customers waiting at the platform or within the moving vehicle. In many cases, in-vehicle interviews will give the surveyor more time to obtain answers. Telephone surveys are also possible but can be less focussed in terms of targeting actual customers. However, telephone surveys can be a highly useful means to understand the impressions of persons who do not regularly use the system. Understanding the concerns of those utilising other modes can be quite useful in terms of gaining future passengers.

Surveys are quite useful in providing a balanced picture of what is important for system users, with standardised measurements of different service features. User surveys can be part of the feedback mechanisms used to award bonuses to system operators, as service quality is the ultimate goal.

10.1.6.5 Public representation

In addition to all the mechanisms used to solicit information from the users, formally electing users' representatives to the system oversight agency can be quite useful. Such representation may be in the form of a public ombudsperson or members of the system's board of directors. By permitting such official representation, the system is providing more transparency and openness to its decision-making processes.

Fig. 10.20
Staff of Bogotá's TransMilenio applaud international visitors viewing the system.
Photo by Lloyd Wright

Further, as noted earlier, in many cases public inputs are more insightful than those of the so-called experts. By allowing citizens to feel more ownership over their public transport system, there is both greater acceptance of the system and greater patronage.

Choosing the appropriate representative can be potentially awkward. In many instances, the position may not warrant the cost and effort of fully democratic elections within the metropolitan area. However, for some cities, the position of ombudsperson can in fact be democratically elected. Alternatively, leading civic and non-governmental organisations can be approached in order to garner suggested names. Likewise, organisations such as the Chamber of Commerce and chapters of engineering, architectural, planning or other professional associations may also be appropriate for consultation and inclusion.

10.2 System professionalism

"A professional is someone who can do his best work when he doesn't feel like it."
—Alistair Cooke, journalist and commentator, 1908–

10.2.1 Public transport staff

In public transport, as in life, sometimes a simple smile or kind word can make all the difference. The role of public transport staff in making customers feel respected and welcome is one of the most powerful promotional tools available (Figure 10.20). While staff behaviour is probably one of the lowest cost ways of practicing good customer service, it is also sometimes one of the most neglected.

Public transport staff training in social interaction skills should be undertaken on a regular basis. Establishing a positive environment between staff and customers is not only healthy when attracting ridership but it can also improve employee morale. For fare collection agents, conductors, and drivers who handle thousands of passengers per day, each customer may become just another face in the crowd. However, a customer's brief interaction with staff can significantly affect their opinion of the service. Thus, it is important that public transport staff view each interaction with care. A customer service training programme should emphasise these points (Figure 10.21).

Additionally, performance evaluations of public transport staff should reflect the importance of excellence in customer interactions. Staff members who excel in customer relations can be rewarded through salary incentives.

In many instances, the staff will not be public employees. The growing trend towards the use of private sector concessions means that these employees will be responding to the demands of their private employers. However, this situation does not imply that the public agency cannot influence positive interactions between transport staff and customers. Financial incentives in concession contracts can encourage appropriate behaviour. Staff training on customer interaction can be imposed as a mandatory requirement for the concessioned firm. Maximising profits can be a strong incentive for private firms to encourage a positive customer environment and a growing customer base.

Key customer interactions may occur at several points throughout the public transport experience:

- Fare collection and fare verification process;
- Customer information;
- Interactions with on-board staff;
- Security personnel.

Fare collection is typically the first point of interaction between customers and staff. A combination of professionalism and friendliness can bolster a person's first impression of the system. A welcoming "hello" and a smile can be an effective personal touch that does little to slow down the overall process. As one enters and leaves the Osaka Monorail system, a staff person bows in thanks for using their system (Figure 10.22). Likewise, in the Keihan railway system in Osaka, customers are created by friendly and helpful staff at the system entrance (Figure 10.23). Obviously, such practice is in part due to the cultural context, but similar acts of appreciation are likely to be possible in a variety of situations.

Responses to basic customer needs such as fare options, questions on routing, and the availability of change should be well prepared and rehearsed. Fare collection services should be well staffed in order to avoid long queues, which may actually discourage persons from approaching a station.

Having available staff, dedicated exclusively to customer information, is a worthwhile investment. The presence of such staff in and

Fig. 10.21
Employee training in Bogotá.
Photo by Lloyd Wright

Fig. 10.22
Each person entering the Osaka monorail is greeted with a polite bow from a company employee.
Photo by Hiroto Inoi

Fig. 10.23
Customers entering the Keihan railways system in Osaka are greeted by helpful staff.
Photo courtesy of Keihan Railways

Fig. 10.24
"Concierge" staff in the Osaka Keihan system make customers feel important.
Photo courtesy of Keihan Railways

Fig. 10.25
A TransMilenio staff person provides assistance to customers.
Photo courtesy of Libros al Viento

around the station can act as a significant public relations boost for a system (Figures 10.24 and 10.25). Staff members can approach customers who look confused or appear unsure of how the system works.

In Bogotá, the "Mission Bogotá" programme is an example of a customer assistance programme that also works as a highly successful social upliftment initiative. Many of the participants in Mission Bogotá were individuals who were previously disenfranchised from society. Those who were formerly homeless, suffering from substance abuse, or otherwise working on the streets are given an opportunity to contribute to society through social service. Through training and confidence building, the participants are dispatched to the streets with their blue and orange uniforms, responding to public needs with a smile and in a professional manner (Figures 10.26). The programme provides the participants with a salary and many new skills.

Fig. 10.26
Mission Bogotá staff provide customer information assistance at TransMilenio stations.
Photo by Lloyd Wright

As part of their duties, the Mission Bogotá team provides customer service duties at TransMilenio stations.

Security personnel can also serve public relations functions in addition to keeping public order. However, in some instances, public transport security staff report to the local police department or other entity. Thus, it is imperative that the public transport organisation works with these other departments to ensure that the security staff is appropriately trained. Training should include knowledge on the functioning of the system and inter-personal skills for interacting with the public. A customer is not likely to make a distinction between public transport staff and security staff and thus will form an opinion on the system based on their interactions with all system personnel.

Having smartly-styled uniforms for all personnel also helps in raising the public's perception of system quality and professionalism. Uniforms that are comfortable and project a stylish image can help change how the customers view public transportation.

10.2.2 Cleanliness

System cleanliness and hygiene is another seemingly trivial issue that has a major impact on customer perception and satisfaction. A public transport system strewn with litter and covered in graffiti tells the customer that the service is of poor quality. Such a scenario reinforces the general notion that public transport customers are somehow inferior to private vehicle owners. Conversely, an attractive and clean environment sends the message that the system is of the highest quality (Figure 10.27). Such a level of aesthetic excellence can help convince members of all income groups that the public transport system is an acceptable means of travel. Ideally, the public transport system will come to be viewed as an oasis of calm and tranquillity in an otherwise chaotic world. Reaching this state of aesthetic quality merely requires good planning and design.

A combination of vigilance and maintenance is an effective strategy to avoid littering and graffiti. Strict policies with financial penalties for disobedience should be prominently employed. Additionally, any incidence of litter or graffiti should be cleaned up as soon as it is identified (Figure 10.28). This sort of immediate response helps to overcome the so-called "broken window" theory of policing. The broken window theory says that if one window in a building is broken and goes unfixed, then in a short time all the windows will be broken. However, if the window is promptly repaired, then further incidences are greatly reduced. The idea is that small-scale problems can grow into large-scale lawlessness when the problems are left to fester. Litter left untouched sends a psychological message to customers that it is acceptable to leave rubbish about.

Fig. 10.27
The cleanliness of this terminal in São Paulo sends a positive message to customers.
Photo by Dario Hidalgo

Strict cleaning schedules are a low-cost way of maintaining a positive public transport environment and customer confidence in the system. On Quito's "Ecovía" line, vehicles are cleaned after every pass along a corridor. Once a vehicle reaches the final terminal, a cleaning team goes through the vehicle leaving it spotless in about four minutes (Figure 10.29). This practice reduces the time night-time cleaning teams need to spend on vehicles. Maintaining spotless operations also sends a message to the general public that littering is not tolerated, which tends to reduce the generation of trash. Likewise, a systematic cleaning schedule for stations and

Fig. 10.28
After just a few weeks of operation, every station along the Parajitos busway in Santiago is covered in graffiti.
Photo by Lloyd Wright

Fig. 10.29
BRT vehicles in Quito are cleaned after each pass along the corridor.
Photo by Lloyd Wright

terminals can also serve to keep a system in near pristine form. While one option is cleaning only after system closing times, in highly frequented systems, it is quite likely that cleaning will also be needed during the day. Thus, scheduling cleaning activities in stations just after peak periods can a way of addressing litter accumulation without interfering in the free flow of customers.

Providing trash receptacles is another helpful option when combating litter, but in some instances security concerns limit their availability or feasibility. Since public transport has unfortunately become a target of acts of terrorism, hidden compartments, such as trash bins, are often too dangerous in places with large numbers of people. Alternatively, the provision of trash bins just outside of the stations is generally a safe and viable option. If the bins are placed in a consistent and well-demarcated space outside of the station, then customers will be able to have an option for disposing of trash.

Public transport facilities also offer the opportunity to effectively market and implement broad recycling programmes. Since public transport systems are likely to be one of the most frequented places in the city, synergies with other public campaigns, such as recycling, are a natural fit. The provision of multiple bins that allow for the separate disposal of glass, paper, metals, plastics, organic materials, and other items can be readily accomplished in conjunction with the public transport system. For example, Singapore's metro system maintains this sort of recycling programme near system entrances (Figure 10.30).

Fig. 10.30
Public transport systems offer a great opportunity to coordinate with other public programmes such as recycling initiatives. Photo shows recycling bins outside a Singapore metro station.
Photo by Lloyd Wright

10.2.3 Food and drink

The consumption of food and refreshments within a public transport system would appear to be a relatively innocuous issue. However, the decision on whether to permit such consumption within the system is a source of debate amongst public transport professionals. On the one hand, permitting food and beverages would seem to be a simple act of customer service that essentially allows another value-added activity during travel. The convenience of a snack between destinations can help a customer's time efficiency and make for a happier patron.

Despite these advantages, there is a substantial negative to food and beverages within the system. The price for allowing food and drinks on board can often be a deterioration in system cleanliness and in the long-term quality of the infrastructure. Stains resulting from spills can become a permanent addition to vehicle and station surfaces. Further, BRT may particularly susceptible to spills due to the ride conditions being more uneven than rail systems. Beyond the damage to vehicles and station infrastructure, food items can also make conditions unpleasant for other customers due to odours. For these reasons, many systems have banned open food and beverage items. The Washington Metro has maintained its high-quality vehicle interiors since the system's 1976 opening. Washington's success in this area is in large part due to its zero-tolerance policy regarding food and drink. Security personnel once famously arrested a person for peeling a banana on board.

The decision to permit food and/or drink can also be somewhat dependent on the cultural context. In parts of South Asia, there may be a significant custom of permitting food and drink in public transport. In such circumstances, a public transport operator may not be able to realistically deny permitting such items. Such systems, though, must make particular effort in terms of highly-frequent system cleaning. Spilled items that remain unattended do much to harm a system's image.

This section has discussed many activities that a public transport system may want to prohibit such as eating, drinking, making a mobile telephone call, etc. (Figure 10.31). Clearly, there may be good reasons to impose such restrictions. However, system developers must maintain a balance between preserving the quality of the system and giving maximum freedom to the customer. If the staff-customer interface is principally a list of things not to be done, then the system may appear in somewhat heavy-handed terms to the public. Thus, it is quite important to focus on the most important restrictions (such as eating and drinking) and to do so in a clear and friendly manner.

10.3 Safety and security

"I don't worry about crime in the streets; it's the sidewalks that I stay off of."

—Johnson Letellier, comedian

10.3.1 Safety

Of the 1.2 million annual deaths that arise from vehicle accidents in the world, the vast majority involve privately owned vehicles. Nevertheless, a single accident involving a public transport vehicle will make considerable news in comparison to the daily occurrence of car-related accidents. An accident involving public transport evokes emotions about governmental responsibility and public safety. The negative stigma that comes from an accident can greatly diminish the public's trust and positive perception of the public transport system. Thus, maintaining high safety standards is fundamental.

Regular vehicle inspections, strict maintenance procedures, and required driver training are all basic elements of a safety programme. Driver behaviour can also be positively reinforced through financial incentives or reprimanded via speeding and other driving violations. Making clear evacuation instructions and fire protection equipment available sends a visible reminder to customers of safety preparedness and professionalism.

10.3.2 Security

Like any public place with large quantities of persons, buses can attract the wrong elements.

Fig. 10.31

Signage in a station of the Quito "Trolé" line indicating the prohibition of certain activities, such as eating and drinking.

Photo by Lloyd Wright

The close confines of crowded conditions provide the ideal environment for pick-pocketing and other assaults on person and property. Fear of crime and assault is a highly motivating factor in the movement towards more private modes of transport, especially for women, the elderly, and other vulnerable groups.

However, crime and insecurity can be overcome with the strategic use of policing and information technology. The presence of uniformed security personnel at stations and on buses can dramatically limit criminal activity and instil customer confidence. Further, security cameras and emergency call boxes (Figures 10.32 and 10.33) can both allow for more rapid responses to potential threats and can also deter crimes from happening in the first place.

An even more worrying issue is the rise of large-scale attacks on buses, such as the hijacking and murder that took place in front of television cameras in Rio de Janeiro, Brazil in 2000. This event has been made into a film called Bus 174. Crime and terrorism in cities such as Rio de Janeiro and Tel Aviv has had a chilling effect on system ridership. Israel has lost approximately one-third of its public transport ridership in just a two-year period (Garb, 2003). While not every

Fig. 10.32

The emergency call boxes in Ottawa BRT stations help to reassure passengers about security arrangements.

Photo by Lloyd Wright

Fig. 10.33
Security cameras, as shown here in Osaka, can do much to prevent crime as well as facilitate a rapid response in case an incident does occur.
Photo by Lloyd Wright

act of violence can be easily deterred, there are design features that can be helpful. Furthermore, a highly visible presence of security staff and the watchfulness of passengers can reduce the probability of attacks (Figures 10.34 and 10.35).

In addition to the presence of security personnel and cameras, good-quality lighting can do much to prevent and discourage criminal activity (Figures 10.36). If hidden areas in around stations are obscured by darkness, then customers may be vulnerable to attack and/or robbery. Well-lit stations are particularly vital in attracting certain user groups to the system. Women may avoid using the system at night if the area gives the impression of insecurity. Attractive lighting can also be another element in creating a public transport system that helps to enhance public space.

Security also affects the type of items customers may bring on board the vehicle. Systems may elect to ban certain types of bags and luggage

Fig. 10.34 and 10.35
The presence of security staff in cities such as Bogotá (left photo) and Quito (right photo) sends an important message to customers about the security of the public transport environment.
Photos by Lloyd Wright

Fig. 10.36
High-quality lighting in Pereira (Colombia) creates a secure environment as well as acts to enhance public space.
Photo courtesy of the Municipality of Pereira

due to security concerns over their contents. The Delhi Metro bans large carry-on items for both security and space reasons (Figure 10.37).

Fig. 10.37
The Delhi Metro bans large carry-on items, which improves system security but can be inconvenient for some customers.
Photo by Lloyd Wright

However, clearly this type of ban will limit the system's usefulness to customers who have an occasion to transport large carry-on items. In many cultures, the ability to board with personal and commercial goods is fundamental to making public transport relevant to low-income users (Figure 10.38). In cases where local practices necessitate the ability board with goods but security threats are present, pre-board security inspections are an alternative. The Manila LRT and MRT systems allow employ security staff to inspect every purse and bag being brought into the system (Figure 10.39). While this type of 100 percent inspection does improve certain security threats, it can be costly to the system operators and time-consuming to customers. Random inspections are another option in which purses and bags are screened but only for a random number of customers.

10.4 Amenity features

"A market is never saturated with a good product, but it is very quickly saturated with a bad one."

—Henry Ford, founder of Ford Motor Company, 1863–1947

Transport is not just about transport. The time available during travel can be used effectively by the customer. A major advantage of public transport over private vehicles is that the time in-transit can be used for other value-added activities such as reading, talking with friends, and relaxing. Amenity features can help to make the most efficient use of this value-added time.

Fig. 10.38
The ability to bring large goods onto the vehicle can be important for low-income users who must access employment with public transport, as shown in this image from Quito.
Photo by Lloyd Wright

10.4.1 Comfort and convenience

Comfort and convenience issues can greatly affect ridership levels, especially amongst discretionary riders. Comfort is affected by the quality of the waiting space at stations, the interior of the public transport vehicles, and the overall environment of the system. Convenience refers to the proximity of stations to useful destinations as well as to how easily customers can reach stations from points of origin. Convenience is closely related to the transport concept of "accessibility".

Fig. 10.39
The 100 percent screening of passenger belongings prior to entering the Manila MRT system reduces security threats, but can create significant passenger delays.
Photo by Lloyd Wright

Comfort, in the general public transport environment, can depend on the amount of personal space available for each customer. If peak hour services result in closely packed stations and vehicles, then the customer is subjected to discomfort and reduced security. Thus, the appropriate sizing of stations and vehicles and the provision of sufficiently frequent services are part of achieving a comfortable system.

Inside the vehicle, the amount of seating available and the type of seating plays a role in comfort. The trade-off between seated space and standing space depends on system capacity requirements. However, even if standing space is predominant due to capacity demands, the quality of the standing space can also be enhanced. Adequate holding straps and sufficiently wide corridors in the vehicle interior can improve standing conditions. Padded seating materials, such as cloth, can add cost to vehicle purchases, but should at least be considered, especially if travel distances are relatively long.

The provision of station seating partly depends on the nature of the service. In high capacity, high frequency services, it is unlikely that seating will be required at stations and terminals, since wait times are relatively short. The developers of the Bogotá system elected to forgo station seating in order to encourage passenger turnover. Seating can also consume valuable space in stations. In some instances, the presence of seating can obstruct boarding and alighting movements, and thus reduce throughputs in stations. However, in cases when wait times are relatively long, some form of seating or support device can be warranted to avoid "standing fatigue". One space saving solution is a leaning bar that permits waiting passengers to partially sit while leaning against a slanted bar. The bar can be padded to increase comfort. While a leaning bar is not as comfortable as a formal seat, it can be an effective alternative. The leaning bars can also avoid problems with individuals who choose to sleep on rows of seats.

Waiting time can also be a factor in designing fare collection and fare verification areas. The best solution is to provide adequate capacity in the fare collection system in order to avoid significant queuing. However, in some instances, such as fans departing from a sporting event, entry queues are unavoidable. Queue guideways may be useful mechanisms to ensure orderliness, fairness, and clarity for waiting passengers. Video displays showing information or entertainment can be another option to reduce waiting stress for queuing passengers.

In many developing cities, the local climatic conditions can warrant climate control devices in the stations and vehicles. Air conditioning can make a significant difference for travel in tropical conditions. Likewise, heating can be important for colder climates. In order to compete for discretionary commuters who may have climate control devices in their private vehicles, such devices in public transport systems can be quite influential. However, there are both capital and operational cost considerations. For instance, air conditioning adds marginally to station and vehicle construction costs and can reduce fuel efficiency by 15 to 25 percent in operation. Further, adapting stations to climate control devices inherently implies design restrictions. Stations must be closed and relatively sealed, and thus will likely require a sliding door interface at bus boarding zones. Again, this feature creates additional costs and also requires additional maintenance and complexity issues within the system. There are also less costly climate interventions, such as passive solar design and spray misting that can be helpful. Chapter 11 (*Infrastructure*) provides more discussion of such design options.

10.4.2 Hours of operation

The system's opening and closing time affects both customer utility and cost effectiveness. Ridership levels during early morning and late evening operations may be somewhat limited. However, the lack of service during non-peak hours undercuts the system's overall usability, which will negatively affect ridership during other times. The need for comprehensive utility does not imply systems must operate for 24 hours. In fact, many public transport systems with 24 hour service experience significant security problems (*e.g.,* robberies, assaults, graffiti, etc.) during late night and early morning hours.

The appropriate hours of operation are likely to be based around the schedules of the major employment, educational, and leisure activities of the local citizenry. Thus, operating hours will depend on key local indicators, including:

- Working hours of major employers;
- Start and closing hours of educational institutions (including night classes);
- Closing times for restaurants, bars, cinemas, and theatres.

The appropriate operating hours will depend upon local cultural and social practices. In Bogotá, the TransMilenio system operates from 05:30 until 23:00, reflecting the relatively early start to the work day that is customary there.

The hours of operation may also be determined by labour laws and expected contractual arrangements with public transport staff. If local labour laws are flexible towards part-time employment, then the public transport operators may have greater flexibility in matching the demand and supply of services.

Scheduling late evening and early morning services may also necessitate arranging for different levels of non-peak service. For example, the frequency of non-peak services in the early evening (*e.g.,* 19:00 to 21:00) may be greater than the frequency of non-peak services at later times (*e.g.,* 21:00 to 24:00). The frequency of service may also increase briefly during late periods, such as the period immediately following the closing of restaurants and bars. The principal aim is to maximise customer utility while simultaneously ensuring the cost-effectiveness of the system.

10.4.3 System aesthetics

Beauty is something rarely associated with public transport. And yet, public transport is in many respects a significant part of public space. Utilising this space in an aesthetically-pleasing manner can do much to improve a city's image and the well-being of its citizens.

The design and appearance of infrastructure components can do much to create a pleasing environment. Design factors such as the use of light, materials, art, and interior design can all project an ambiance of calm, clarity, and comfort (Figures 10.40 and 10.41).

Art exhibits within systems can do much to change how the public views the system (Figures 10.42, 10.43, and 10.44). Such efforts can help to attract different types of customers who may not ordinarily consider public transport as a desirable option. Artwork can also help to create a calming and stimulating environment for customers. Exhibitions also provide numerous opportunities for interaction between the public transport system and local schools.

Fig. 10.40
The use of light at the Villa Flor station in Quito creates a beautiful atmosphere for public transport users.
Photo courtesy of El Comercio

Fig. 10.41
Public transport infrastructure can be designed to enhance and not detract from the quality of public space.
Photo by Lloyd Wright

Fig. 10.42, 10.43, and 10.44
Artwork within the public transport system can be an inspiring choice for improving the customer's travel experience.
Clockwise from top left:
1. Art gallery within the Osaka monorail system
Photo by Lloyd Wright
2. Wall art in the Tokyo subway
Photo by Lloyd Wright
and
3. Sculptures in the Lisbon subway
Photo courtesy of UITP

10.4.4 On-board news and entertainment

It has been noted that entertainment systems such as video can be effective in stemming passenger impatience and anxiety during waiting periods. Video presentations at station areas may include news, weather, music videos, and customer information announcements. Audio systems are also an option. Music can be played within stations and buses.

In 2005, the Atlanta rail systems, MARTA, added video screens to all of its rail cars. The service provides news and entertainment to customers. In return, the MARTA system is receiving US$ 20 million over a ten-year period from the associated advertising revenues (McLaughlin, 2005).

Likewise, the Üstra system in Hanover (Germany) has equipped its vehicles with monitors. In this case, two screens are provided in each vehicle. One screen is devoted to providing customer service information, such as information about the next stop, possible transfer options, journey times, and updates related to any travel incidents (Figure 10.45). The other screen provides entertainment and news programming (UITP, 2005). Likewise, the Orlando Lymmo system has teamed up with a firm called Transit TV to provide on-board news and information (Figure 10.46).

Fig. 10.45
Information displays on the Hanover Üstra system provide system information, news, and entertainment.
Photo courtesy of UITP

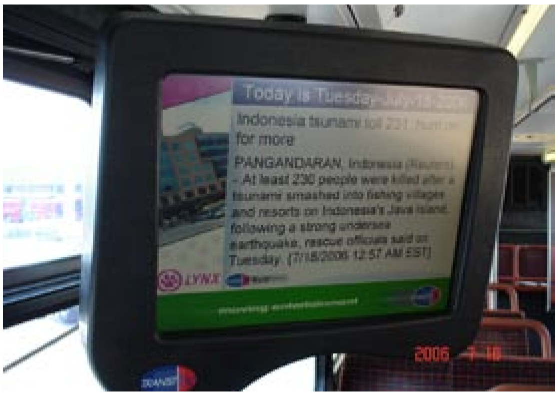


Fig. 10.46
"Transit TV" keeps Orlando system users up-to-date with the latest news.
Photo courtesy of Doug Jamison, Orland LYNX

While some customers will find video and audio entertaining and useful, this reaction is not always shared by all. For some, visual and aural displays contribute to an increased level of distraction and chaos in the public transport experience. One person's symphony is another's needless noise. In Quito, music on BRT vehicles was suspended after students complained that it was difficult to study with the noise. Customer groups in Hong Kong formed in protest to the playing of music in vehicles (Figure 10.47). Thus, care must be exercised when using certain entertainment features such as video and audio. The decision can be quite dependent on local customs and preferences. Moreover, like all such devices, video and audio systems involve costs, both in terms of the initial investment as well as in the long-term maintenance.

Fig. 10.47
Campaign material from the "Hush the Bus" programme in Hong Kong. Ensuring a quiet environment inside the bus helps customers who want a pleasant public transport experience.
Image courtesy of Hush the Bus programme, Hong Kong

10.4.5 Wired stations and vehicles

The advent of communications technologies such as the internet, email, and mobile telephones have revolutionised how people do business and how people interact with others at a distance. Public transport can offer services that take advantage of these communication technologies. Some public transport systems are already beginning to offer free wireless internet services to their customers. The wireless feature can be supplied into vehicles and stations via transmitter technologies. The Osaka Monorail provides free wireless access within some of its stations (Figure 10.48).

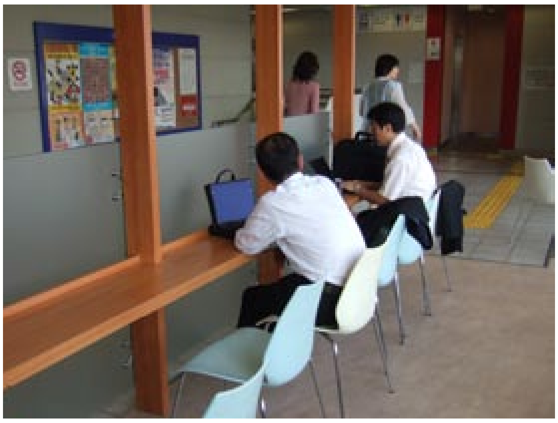


Fig. 10.48 and 10.49
The Osaka monorail provides both free wireless internet connections as well as for-pay PC workstations.
Photos by Lloyd Wright

For patrons without their own notebook computer, personal digital assistant (PDA), or other handheld device, the Osaka system also provides PC workstations with for-pay internet access (Figure 10.49).

While internet and email access may seem a needless extravagance in a developing-city public transport system, cities wishing to attract current private vehicle users may find the technology of great value. Further, as information technologies continue to fall in cost, the concept is not entirely out-of-reach for developing cities.

Making effective use of digital technology within a vehicle, though, does imply the ride conditions are sufficiently smooth to permit suitable work conditions. Likewise, a smooth ride is also a preferred state for any variety of on-board activities including reading, studying, writing, and relaxing. Both the vehicle technology and road conditions are principal determinants in the suitability of the environment for these activities. Thus, well-suspended vehicles in conjunction with level and well-maintained road conditions provide the best conditions. Nevertheless, in general, rail technologies provide smoother ride conditions than bus-based technologies such as BRT.

Fig. 10.50
Public telephone in a Quito Trolé station.
Photo by Lloyd Wright

10.4.6 Telephone services

The availability of telephones within a public transport system can also be a much-valued service. A person waiting within a station or on-board a vehicle can take advantage of a telephone service to call home or to conduct business. Systems such as Quito provide a public telephone within each station (Figure 10.50).

The use of mobile telephones within the public transport system can also be of great utility to customers. Mobile technology is another easy means to stay in touch with the office or with friends while using public transport. In some circumstances, system developers may wish to provide special receivers to allow mobile connections in otherwise blocked areas such as tunnels.

However, telephone usage may also raise the same concerns, over quiet, as video and audio systems. The ringing of telephones and ensuing loud conversations can be a serious distraction to those passengers looking to study, work, or simply relax. Thus, some discretion over the use of mobile technology is advised. Again, any sort of restrictions would be highly dependent on local preferences and customs.

10.4.7 Reading materials

As noted earlier, public transport systems frequently perform services beyond moving persons between two points in a city. Systems in cities such as Bogotá and São Paulo have initiated impressive literacy projects through the provision of free reading materials. By making books freely available to customers the systems are promoting reading as a pastime and also allowing customers to undertake another value-added activity during their journey.

The Bogotá programme is known as "Libros al Viento" (Books in the Wind). In this case, books are available to customers at TransMilenio stations and terminals (Figures 10.51 and 10.52). Customers may freely take the books and even make use of them at home or any other location outside the system. However, customers are encouraged to return the books to the system after being read. Remarkably, after two years of existence, the programme has reported that only one book has failed to be returned. This success factor perhaps speaks much to the respect the citizens give to the BRT system.

The provision of free newspapers is an increasingly popular service provided in several public transport systems worldwide. The "Metro" newspaper in London and other cities is one of the best known examples (Figure 10.53). In some instances, the newspaper is circulated as a private sector initiative, with the private company receiving revenues from advertising. In other instances, the public transport company itself initiates

Fig. 10.51 and 10.52
The "Libro al Viento" programme in Bogotá provides free books and literature to TransMilenio customers.
Images courtesy of "Libro al Viento"

Fig. 10.53
The "Metro Hoy" newspaper provides patrons of the Quito Trolé line with news and information.
Photo by Lloyd Wright

the newspaper publication and distribution as a service to their customers (UITP, 2005).

10.4.8 Public services

Finally, there are some services that system developers may wish to provide customers as a courtesy. The provision of restrooms, baby changing facilities, lost and found offices, and emergency aid offices are examples. Opinions on whether to provide restrooms in a system can vary. If a system includes several hundred kilometres of runways and possible long commute times, then the provision of restrooms should be considered for patrons. Baby changing areas can also be quite appropriate in such circumstances. System developers in Bogotá elected to forgo restrooms based on a philosophy of wanting to keep passengers moving through the system without stopping.

Restrooms and other facilities also involve capital and operating costs. Public restrooms are particularly susceptible to vandalism and physical deterioration which undermines the image of the overall system, as well as the facility's functional utility. Nevertheless, a well maintained facility at major terminals may be a modest cost to provide adequate customer service, such the ones available in the new Passa Rápido Terminals in São Paulo or in the central bus terminal of Nagoya (Figure 10.54).

Lost and found facilities are also an important service that people can reasonably expect to be provided in major public transport systems. The location of a lost and found office should be well noted in system literature and at certain signage points.

The provision of lockers can also be a convenient service to customers. Rather than carrying items for long periods during the day, a customer may prefer to store an item for a later retrieval. Lockers also represent a potential revenue source that can ultimately fund other aspects of a system. However, lockers also present difficulties that may not warrant their usage. Given security concerns in many of today's cities, the unknown nature of a locker's contents can pose a threat. Further, there are costs associated with the management of the locker system and the maintenance of the lockers. Policies and procedures must be developed regarding items left over-night or for long periods. Thus, the value of any customer service programme must be weighed against its potential costs. Nevertheless,

Fig. 10.54
The provision of high-quality restrooms at the central bus terminal in Nagoya greatly serves customer needs.
Photo by Lloyd Wright

there should always be an inherent bias towards maximising service to the customer.

10.5 Segmentation of services

"I'll go through life either in first class or third, but never in second."

—Noel Coward, actor, composer, and playwright, 1899–1973

No two customers are exactly alike. Each person has their own transportation patterns and habits as well personal preferences for comfort, convenience, and affordability. In some cities of the world, services are segmented to offer different public transport characteristics to more closely match specific customer preferences. Thus, in Hong Kong and Bangkok, premium air conditioned bus services are offered to persons who are willing to pay more. In the Kolkata metro and the Manila LRT 1 system, women are afforded the option of entering carriages that are women only (Figure 10.55). In Buenos Aires, Rio de Janeiro, and Sao Paulo, executive minibuses provide express services from the city centres to affluent communities. These executive vehicles also tend to offer air conditioning, increased leg space, and more comfortable seating.

The opportunity also exists for BRT systems to offer various types of services to cater to particular groups. The advantage of such segmentation is that it is possible to target groups who may not otherwise travel by public transportation. However, there are also disadvantages. Each layer of segmentation increases system management complexity. Ensuring the correct spacing of vehicles becomes all the more difficult when one is not only managing different routes but also routes plus special features, such as air conditioning. Further, purchasing vehicles with different characteristics can increase overall costs due to the loss of bulk purchasing possibilities. Each permutation of different features (air-conditioning, seat types, interior spacing, vehicle size, etc.) reduces standardisation.

Fig. 10.55
Women are provided their own platform waiting area and own carriages in the Manila LRT 1 system.
Photo by Lloyd Wright

Perhaps more importantly, though, specialised services perpetuate some of the very social divisions that well-designed public transport systems try to overcome. As Enrique Peñalosa, the former Mayor of Bogotá, has noted, "the TransMilenio system is one of the few places in Bogotá where the wealthy and poor meet on an equal basis." This sort of social familiarity helps achieve an important goal of community cohesion and unity in a city. Public transport is a place where all the citizenry (the young, the elderly, and the physically disabled) can experience the city's complete diversity. Instead of providing a high-quality service to the wealthy and a different type of service to the poor, systems like TransMilenio have proven that it is possible to provide affordable excellence in public transport for everyone.