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Bus Rapid Transit Planning Guide

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CHAPTER 11

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11. Infrastructure

"A person should design the way he makes a living around how he wishes to make a life."

—Charlie Byrd, jazz musician, 1925–1999

The physical design of the BRT system begins to give the project a tangible substance that better allows all stakeholders to properly envision the final product. This process also allows the planning team to better estimate the actual capital costs expected for the project.

Infrastructure consists of not only the roadwork that forms the busway but also a range of other components. The infrastructure components include:

- Busway infrastructure;
- Feeder infrastructure;
- Stations;
- Intermediate transfer stations;
- Terminals;
- Depots;
- Control centre;
- Traffic control signals;
- Integration infrastructure;
- Commercial space;
- Public utilities (electricity, gas, water, sewage, telephone, etc.);
- Landscape.

The design and engineering of these components is dependent upon several key factors that will dictate the eventual form of the infrastructure. Theses factors include: cost, functional attributes, and aesthetic design. Like so many topics in BRT, there is no one correct solution to infrastructure design. Much depends upon local circumstances such as climatic and topological conditions, cost structures, and cultural preferences. For instance, what is aesthetically pleasing in one culture will not be considered as such in another.

The physical design and engineering of the system directly follows from the operational and customer service characteristics chosen in chapters 7, 8, and 9. The corridor selected, expected capacities, and service options all influence the physical design. However, the physical design may also exert influence on the operational characteristics as well. Given the varying cost ramifications of different physical designs, several iterations between operational design and physical infrastructure design may be required. Thus, physical or financial limitations that are placed upon infrastructure design can necessitate a revision of the previous work on operational characteristics.

The initial stage in the infrastructure design process is to develop a conceptual design framework for the system. Based upon the inputs from the previous demand modelling and the operational study, the physical location and initial designs are completed for the various infrastructure elements. An initial cost analysis can then be performed to determine the feasibility of the proposed design. Finally, once the conceptual design has been thoroughly evaluated and approved, detailed engineering designs can proceed.

The topics presented in this chapter are:

11.1 Conceptual design and detailed engineering design

"The designer has an obligation to provide an appropriate conceptual model for the way that the device works. It doesn't have to be completely accurate but it has to be sufficiently accurate that it will help in both the learning of the operation and also dealing with novel situations."

—Don Norman, scientist and psychologist

The design of the infrastructure takes place in two basic stages, though in practice it is often more of an evolutionary process. In the first stage, conceptual designs will be developed based on the emerging operational plan. The second stage, the detailed engineering design, follows once the conceptual study and the initial cost estimates warrant a commitment towards a particular design. Thus, for each infrastructure component discussed in this section (*e.g.,* busways, stations, terminals, etc.), the planning team will first complete a conceptual study prior to moving towards more detailed engineering plans and specifications. Most of the conceptual design issues are addressed in the operations chapters. This chapter provides additional detail to the physical design process necessary to complete the conceptual design. Detailed engineering will follow general engineering practice.

11.1.1 Conceptual design

The infrastructure conceptual design should provide a reasonable level of detail so that decision-makers may properly evaluate the cost, functionality, and aesthetics of the proposed system. Thus, the conceptual design will already include overall dimensions of the infrastructure components, basic drawings, and sufficient description to develop an initial cost estimate.

Even for a basic conceptual design, a considerable knowledge of the corridors will be required. A full audit and inspection of each corridor segment will allow the design team to understand the nuances of the corridor as well as identify the most problematic areas. Particular attention should be given to intersections and proposed station locations. It is at these points that the most complicated interactions with private vehicles and pedestrians will take place. Photography and video of the different segments can be an indispensable tool for design and engineering professionals. Recording each segment in a visual format helps to put together the options

Fig. 11.1
Early rendering of the proposed Guangzhou BRT system.
Image courtesy of ITDP

in the office. Likewise, aerial views of each segment can also provide a unique perspective that will aid in the process.

At the conceptual stage, a full range of options should be considered, even if some options appear to not be feasible in financial or technical terms. The conceptual stage is the time for creativity and out-of-the-box thinking. Thus, options such as grade-separation at problematic intersections should at least be given an initial consideration.

The conceptual design stage tends to be both evolutionary and iterative in nature. As each segment of the corridor is analysed in more detail, the physical design will often evolve from one form to another. Further, as decisions taken on one corridor segment will affect other segments and as cost estimates influence the technical options, the design will likely go back and forth through much iteration.

Once this stage is completed, it will be possible to develop fairly accurate artistic impressions and drawings of the system infrastructure. These initial renderings will help decision-makers and interested parties to begin to visualise the system. Figure 11.1 shows an artistic impression for the Guangzhou BRT system.

Likewise, renderings can also form an important input into simulation videos that give decision-makers a fairly realistic idea of the proposed system. Renderings for the proposed Johannesburg Rea Vaya system helped to secure the necessary political support.

Likewise, early renderings in Bogotá helped to communicate the project to a range of stakeholders, including the general public. Figure 11.3 shows an early image that closely approximates the final form eventually taken by the Bogotá TransMilenio system.

The contracting of the design consultants can take on several different forms. In some cases, the design is carried out by one firm while the ultimate construction is to be done by another firm. This option avoids any problems with conflicts of interest between the design and construction work. For example, if the design and construction firm are one in the same, then there could be a tendency to choose designs that minimise construction costs. However, such a design may not be optimum from an operational perspective.

Combining the design and construction work into a single contract, though, does hold some advantages. With a single firm undertaking both these tasks, there is a greater degree of continuity between the design and construction. The single contract also can ensure a greater degree of responsibility in delivering the project. With two contracts, the construction firm may blame the design firm and vice versa if problems arise. In this sense, a single contract can be simpler to enforce from a legal perspective. Phase I of Bogotá's TransMilenio incurred legal disagreements over a failed surface material. The separation of the initial design from the detailed engineering and the construction resulted in various parties accusing others of the fault.

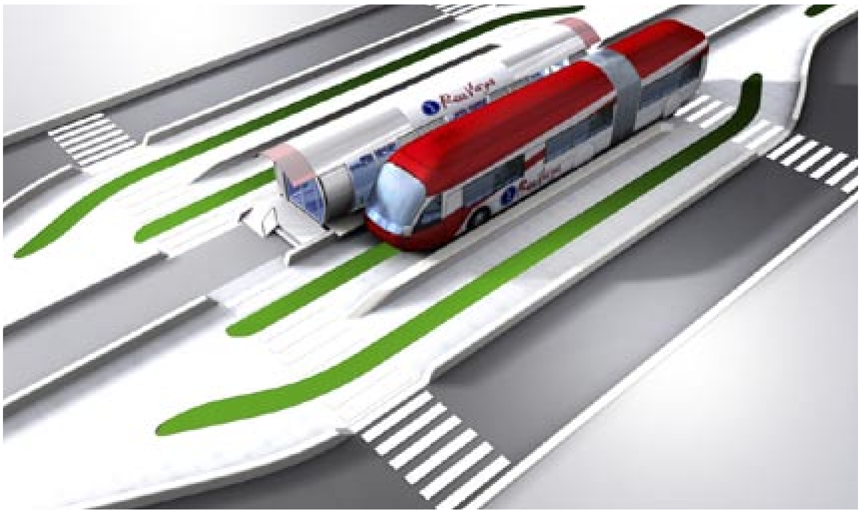


Fig. 11.2
Rendering for the proposed Johannesburg Rea Vaya system.
Image courtesy of the City of Johannesburg

Fig. 11.3
This early rendering of the Bogotá system closely matches the ultimate shape and form of the actual system.
Images courtesy of TransMilenio SA

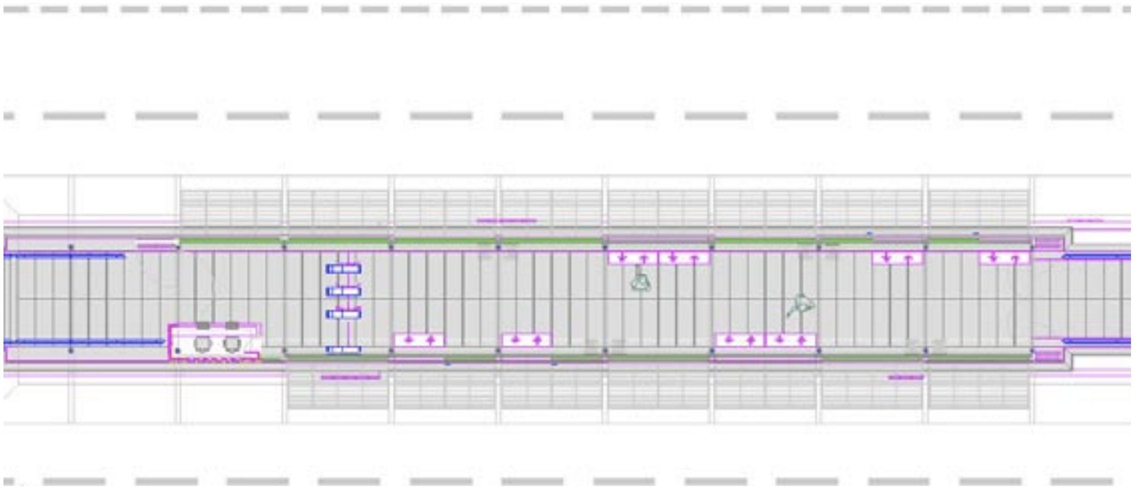


Fig. 11.4
An Autocad drawing of a proposed station for the Barranquilla BRT system.
Image courtesy of the Municipality of Barranquilla

Fig. 11.5
An Autocad drawing of the North Terminal of the Barranquilla system.
Image courtesy of the Municipality of Barranquilla

11.1.2 Detailed engineering design

Once a conceptual design is completed and initial cost estimations are within an acceptable range, then more detailed engineering work can be undertaken. The detailed engineering design and specifications will be the basis for the actual construction work. The detailed design will also permit construction firms to make more accurate cost estimates within the construction bid process.

Given the topographical changes throughout any corridor, each section of roadway will have its own unique design. Detailed drawings generated from software such as AutoCAD will be required along each segment. Other drawings will begin to provide some of the more precise dimensional and structural details that will later be transformed into highly detailed engineering drawings. Figures 11.4 and 11.5 are examples of these types of drawings.

11.2 Runways

"You know more of a road by having travelled it than by all the conjectures and descriptions in the world."

—William Hazlitt, Literary critic, 1778–1830

The construction of the busway will typically represent approximately 50 percent of the total infrastructure costs. Thus, savings through efficient design and material choice can produce significant dividends. Cost savings, though, must be viewed both from the perspective of initial construction costs and long-term maintenance costs. Lower-quality road materials may reduce capital costs but will dramatically increase maintenance costs if roadways need repaving or reconstruction after just a few years.

11.2.1 Surface materials

The principal determinant in choice of runway materials is the axle weight of the BRT vehicles selected for operation and the number of projected BRT vehicles likely to use the infrastructure over the projected service life of the road. The roads must be built to a standard able to withstand the projected usage by vehicles with the specified axle weight. The appropriate choice of specific paving methods and materials that are both affordable and able to sustain vehicles of the specified BRT vehicle axle weight may vary from country to country. Also, one pavement treatment that works well in temperate climates may subside in tropical climates. Local pavement engineers should thus be a part of the decision-making team.

If the BRT vehicles are standard 18.5-metre articulated vehicles, these vehicles are very heavy and unless the vehicle volumes are quite low may require reconstruction of the entire road bed with materials able to withstand these heavier axle loads. The total vehicle weight of the articulated vehicle utilised by the Bogotá TransMilenio system is approximately 30,000 kg and the maximum axle load is approximately 12,500 kg. The vehicle volumes were also extremely high, so busways must thus be constructed to withstand this axle load on a frequent basis.

The weight of the vehicle is most acutely experienced at the station areas, where the vehicle's acceleration and deceleration increases the amount of force on the road bed. The subsiding of the road bed from the weight and force of the vehicles is also a more serious problem at the station stops. Such subsiding can effectively render a station boarding area inoperative. As the roadbed level lowers, the station to vehicle interface will no longer align evenly and a step will form between the vehicle floor and the platform.

In terms of longevity, concrete is typically a better choice than asphalt. Concrete of a constant and reasonable quality is more resistant to the forces of heavy vehicles passing on a frequent basis (Figure 11.6). While concrete is generally more costly than asphalt, the longer life of the surface will likely justify the higher initial cost. Concrete paving if done properly can last 10 or even more with only minor maintenance. By contrast, asphalt often requires resurfacing as often as every two years in tropical climates with heavy use. Because of the additional force at the stations, one cost-cutting option is to consider concrete only at stations. In such instances, the runways between the stations are constructed with lower-cost asphalt.

Other building materials can also be used, though they tend to be more expensive.

Fig. 11.6
Reinforced concrete, as in this example from the construction of the Quito Central Norte line, has much greater longevity than asphalt.
Photo by Lloyd Wright

Fig. 11.7
For aesthetic reasons, Bogotá utilises brick and paving stones in the city centre area.
Photo by Carlos F. Pardo

Fig. 11.8
Due to the weight of the new BRT vehicles, the Jakarta asphalt runway quickly deteriorated.
Photo courtesy of ITDP

Particularly in the city centre, brick and other paving stones are frequently chosen for aesthetic reasons (Figure 11.7). These surface materials also send a useful visual signal to bus drivers that they are in a public space and must operate at safe speeds. Such materials are often quite able to withstand very heavy axle loads with regular maintenance.

Bogotá's TransMilenio resurfaced the entire corridor in concrete and used brick in the city centre. TransJakarta initially used only asphalt and suffered from major problems of the roadway sinking and deteriorating at the stations, so the roadbed at the stations was repaved using concrete (Figure 11.8). For its first two corridors, Quito utilised asphalt on the runways but with concrete at the station areas. The latest corridor to be constructed in Quito, the Central Norte corridor, was built with concrete throughout the system. However, the higher investment in the surface material for the Central Norte line may be one reason that the station infrastructure is of somewhat lower quality than the other two corridors in Quito (Figure 11.9). Thus, one must always weigh the alternative use of the investment when making decisions about any one item, such as surface material.

Fig. 11.9
Quito's high-quality use of concrete on the runways of the Central Norte line contrasts with the relatively lower-quality of the station infrastructure.
Photo by Lloyd Wright

The surface material will only endure as long as the base materials are in tact. If water drainage is insufficient or if the base structure is inherently weak, then the surface material will quickly fail. A poor base design in Bogotá led to the premature failure of the concrete surface on the system's Avenue Caracas corridor. Bogotá has largely relied upon a technique known as "white topping" for its concrete busways. The

Fig. 11.10
In parts of the Hangzhou BRT system, the separator is a fully landscaped median.
Photo by Karl Fjellstrom

Fig. 11.11
In Beijing, metal fencing it utilised at the separator.
Photo by Karl Fjellstrom

white topping method utilises the existing asphalt lane as the base material for the concrete surface material. White topping is thus a fairly economic option since it does not rely upon reconstruction of the busway base. However, the successful application of white topping depends on the strength of the base core, the integrity of the asphalt layer, and the level of cohesiveness between the asphalt and concrete layers.

11.2.2 Lane separation

While some busways are not physically separated from mixed traffic, most are separated by a physical barrier. This barrier can range from a fully landscaped median to simple blocks, bollards, curbing, permanent traffic cones, walls, metal fencing, or other types of barrier devices. The design of the separator should be sufficient to physically prohibit mixed traffic vehicles to enter the busway.

A wall or large landscaped median will provide the most complete protection for the busway, but will make it difficult for vehicles to escape the busway in case of an obstruction (Figure 11.10). Likewise, the metal fencing, as utilised in Beijing, makes it impossible for the BRT vehicles to leave the corridor in case of emergency (Figure 11.11). However, the Beijing fencing does have an advantage as a movable barrier. If the system developers later widen the Beijing busway, then the fencing is relatively easy to relocate.

It may be useful to design the separator to permit buses to leave the busway in case of an obstruction. For example, if a bus breaks down on the busway, it can be useful to allow other buses to leave the lane to avoid being blocked. Thus, a curbing separator that is high enough to dissuade private vehicles from entering but low enough to allow buses to safely leave the busway can be appropriate (Figure 11.12). One option is to employ a curbing material that is rounded on the busway side but forms a sharp edge on the private vehicle side.

Fig. 11.12
In Bogotá, the separator blocks are high enough to discourage intrusions by private vehicles but low enough to allow a BRT vehicle to leave the busway in case of emergency.
Photo by Carlos F. Pardo

If it is likely that at times buses will need to cross the separator, the divider should be built strong enough so as not to break under the wheels of the bus, and also low enough as not to damage the bottom of the bus. In Quito, for example, the stone blocks used as separators are frequently damaged and dislocated, creating hazardous obstacles in the roadway and undermining the barrier function (Figure 11.13). The breakdown of the barrier can then subsequently lead to private vehicles infringing upon the busway, creating safety hazards to both the private vehicles and the BRT customers (Figure 11.14).

Fig. 11.13
In Quito, the separator blocks have been susceptible to damage and deterioration.
Photo by Lloyd Wright

Fig. 11.14
As more separator blocks erode, an increasing number of private vehicles intrude upon the busway, which can lead to serious accidents.
Photo by Lloyd Wright

Fig. 11.15
Curitiba's low curb medians with Portuguese-styled designs in the stones has enhanced the local urban environment.
Photo courtesy of ITDP

Fig. 11.16
Prior to its removal, the wall barriers on the São Paulo Novo de Julio corridor undermined the urbanistic qualities of the corridor.
Photo courtesy of ITDP

Pedestrian safety and aesthetics are other considerations. There are several advantages of using a metre-wide median to separate the busway from mixed traffic if the right of way allows. A metre-wide median allows the median to also serve as a pedestrian refuge for pedestrians crossing the road. A larger median tends to also provide the most aesthetically pleasing and complete demarcation of the busway. Curitiba's BRT system is separated by a low curb filled with decorative Portuguese stone to give an aesthetically pleasing median that provides some pedestrian refuge (Figure 11.15). It was designed to facilitate crossing of the road anywhere along the corridor. In some places, motor vehicle parking in Curitiba is also adjacent to this median divider rather than adjacent to the curb, so the parking lane becomes part of the barrier protecting the integrity of the busway.

Fig. 11.17
Along Bogotá's Alameda Jimenez bollards are used to separate the busway from the pedestrian walkway.
Photo by Diego Velazquez

Walls were originally used in the Santa Amaru/Novo de Julio corridor in Sao Paulo. The walls provided complete protection from encroachments. They were intended to make it impossible for pedestrians to cross the busway except at designated locations. However, the walls were aesthetically unpleasing, and were impossible to escape if a vehicle broke down (Figure 11.16). They also created visibility problems for crossing pedestrians. The walls were eventually completely removed. This significantly improved the aesthetics of the corridor but the busway now suffers from encroachments from motor vehicles.

In pedestrian areas, the use of a separator medium will depend on the volume of BRT vehicles and pedestrians. In some instances, successful pedestrian malls have been created with no discernible separation between the busway and the pedestrian walkway. Instead, vehicle speeds are reduced to allow drivers to react to any pedestrians straying into the busway. However, in high-volume operations partial or even full separation may be appropriate. Along the Bogotá Alameda Jimenez route (also known as the "Environmental Axis") nicely designed bollards act to separate the busways from the pedestrian zone (Figure 11.17).

Table 11.1: Recommended minimum lane widths per direction

Lane type	Minimum recommended width per direction
Footpath	3.0
Cycle way	2.5
Busway lane at station area	3.0
Busway lane along corridor	3.5
Median divider along corridor	0.5
Curb lane for mixed traffic	3.5
Other lanes for mixed traffic	3.0
Station width[1])	3.0

[1]) Station width depends greatly on capacity; the minimum presented here is an actual figure from the Quito BRT system.

11.2.3 Typical BRT corridor cross sections

"The excellence of a road consists chiefly in its being protected from the reigning winds, and the swell of the sea; in having a good anchoring-ground, and being at a competent distance from the shore."

—William Falconer, poet, 1732–1769

11.2.3.1 Standard runway configurations

Standard BRT runway widths have already been discussed in Chapter 5 (*Corridor selection*). This

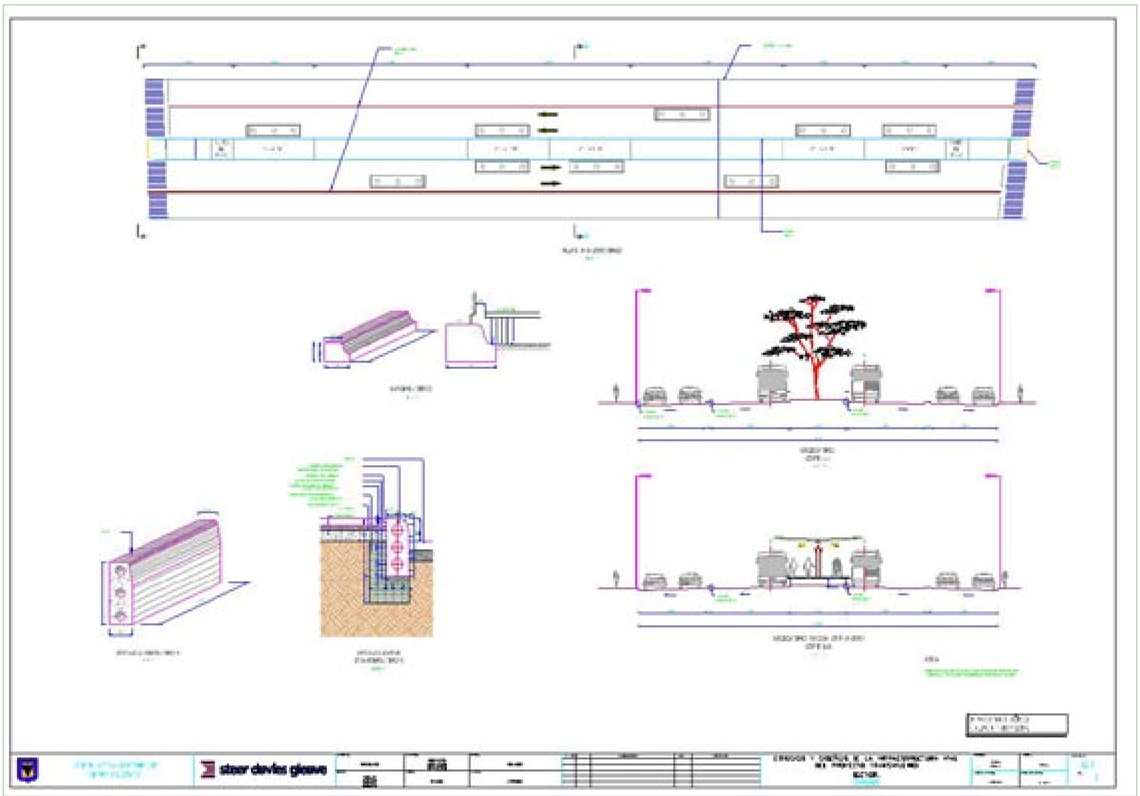


Fig. 11.18

In ideal conditions with wide right-of-ways, such as in Bogotá, the road design can accommodate busways, wide station platforms, and at least two lanes of mixed traffic. This figure shows a conceptual design for a segment of the TransMilenio system.

Image courtesy of Steer Davies Gleave

section summarises some of the common runway configurations utilised in systems to date. Table 11.1 provides general recommendations for minimum lane widths.

The exact configuration of any particular corridor will depend on the level of mixed traffic, the level of pedestrian and bicycle traffic, and the frequency of buses within and outside the BRT system. The methodology for determining how many lanes are needed for each mode is explained in Chapter 8 (*System capacity and speed*). Below are shown some theoretical minimum right of way configurations, as well as a few actual configurations from different systems.

In ideal conditions, the width of the right-of-way will be sufficient for a busway, two mixed traffic lanes, adequate footpaths, and possibly even cycle ways (Figure 11.18). However, as has been noted, BRT systems in cities such as Rouen and Guayaquil have been successfully implemented with just a single mixed traffic lane.

Normally, at least the curb lane tends to be 3.5 metres wide in order to accommodate trucks and any buses not operating within the BRT system. The busway lanes themselves are normally 3.5 metres wide. At the stations, the busway lane can be narrowed to 3 metres because the BRT vehicle is operating at a slower speed and must pull up adjacent to the boarding platform. If a passing lane is provided, however, the total lane width for the two lanes together should be 7 metres.

Footpaths less than 3 metres in width are very uncomfortable for pedestrians, especially if adjacent to a busy street of mixed traffic. While there are places in the Quito BRT system where the footpath is as narrow as one metre, it is not a comfortable walking space. Bicycle lane widths depend on the volume of bicycle traffic, but as a general rule, cycle ways should not be narrower than 2.5 metres per direction (Figure 11.19). If the cycle way is less than this width, cyclists will generally prefer to operate in the mixed traffic lanes.

11.2.3.2 Station areas and intersections

Space is generally at a premium at intersections and at the station areas. Space is a premium at intersections because of turning movements and the potential need for dedicated turn lanes. For this reason, as noted in Chapter 9 (*Intersections and signal control*), it is fairly typical to separate the location of the station from the location of the intersection.

Constraints on space at the stations areas are due to the presence of the station platform in addition to the busway lanes. On some systems with passing lanes, such as on 80th Street (Calle 80) in Bogotá two full BRT lanes are maintained throughout the system. The wide road widths found along this corridor permits the develop-

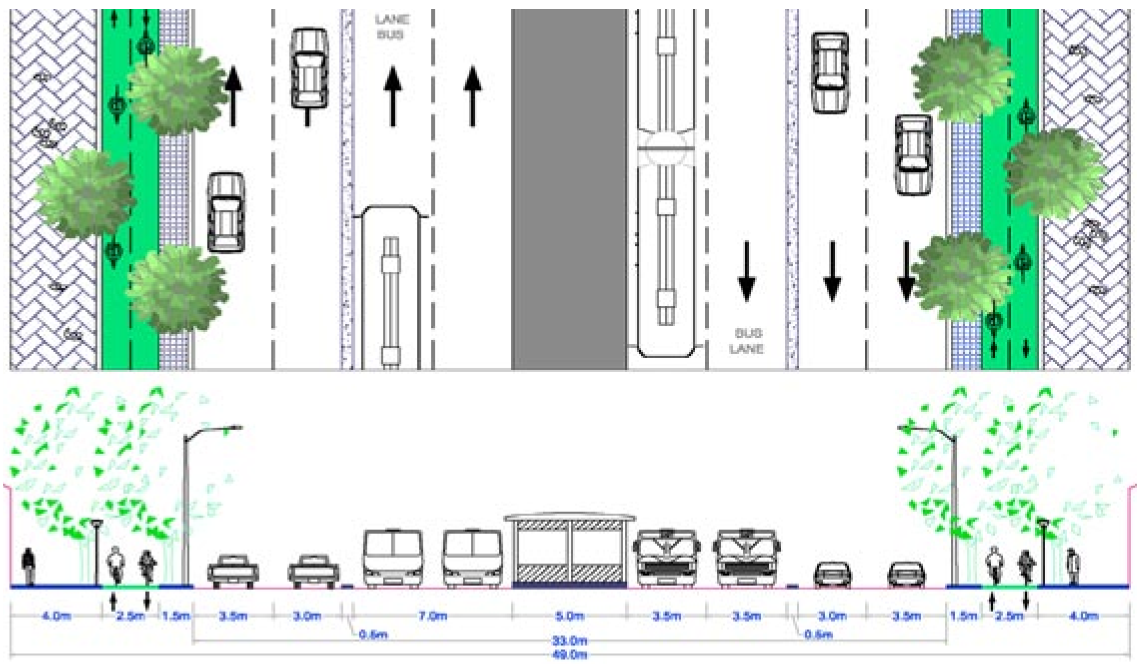


Fig. 11.19
This conceptual design of the Dar es Salaam BRT system (DART), shows the inclusion of 2.5-metre wide cycle ways on each side of the road.
Image courtesy of the City of Dar es Salaam

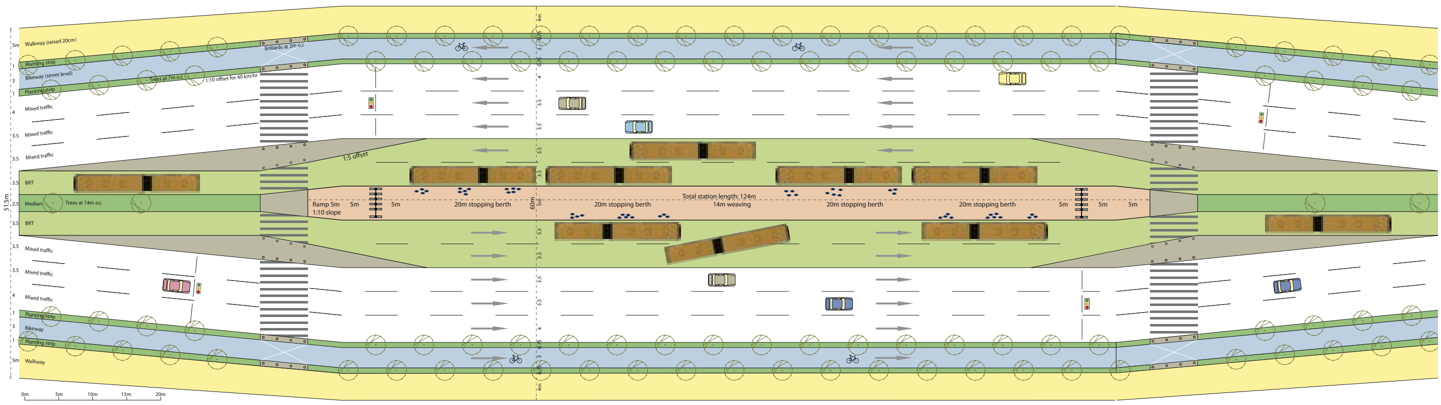


Fig. 11.20
In Guangzhou, the passing lane is provided through a widening of the roadway at the station areas.
Image courtesy of ITDP

ment of two full BRT lanes. This configuration avoids the need to widen and narrow the right-of-way at station locations. In this case, two 3.5-metre wide BRT lanes are provided in each direction throughout the corridor.

In some areas where right-of-way space is limited, such as Avenida Caracas in Bogotá and along the phase one corridors of Dar es Salaam and Guangzhou (Figure 11.20), a passing lane is provided only at station areas. Outside the station areas, only a single lane of busway is provided for each direction of travel. This configuration helps to minimise the cost of possible land acquisition along the corridor. If there is plenty of right-of-way, this configuration allows for additional turning lanes for mixed traffic at intersections. The configuration also allows for a median between the busway and the mixed traffic lanes that can serve as a pedestrian refuge, and for wider footpaths and bike lanes at non-station locations.

The required width can be mitigated somewhat by offsetting the location of the sub-stops for each direction of travel (Figure 11.21). This configuration reduces the required road width by one lane and still delivers full passing capabilities at the station. Of course, this configuration does elongate the station and also introduces a slight turn at the station area. Nevertheless, in cities with restricted road widths, this design can be effective in permitting passing lanes at stations.

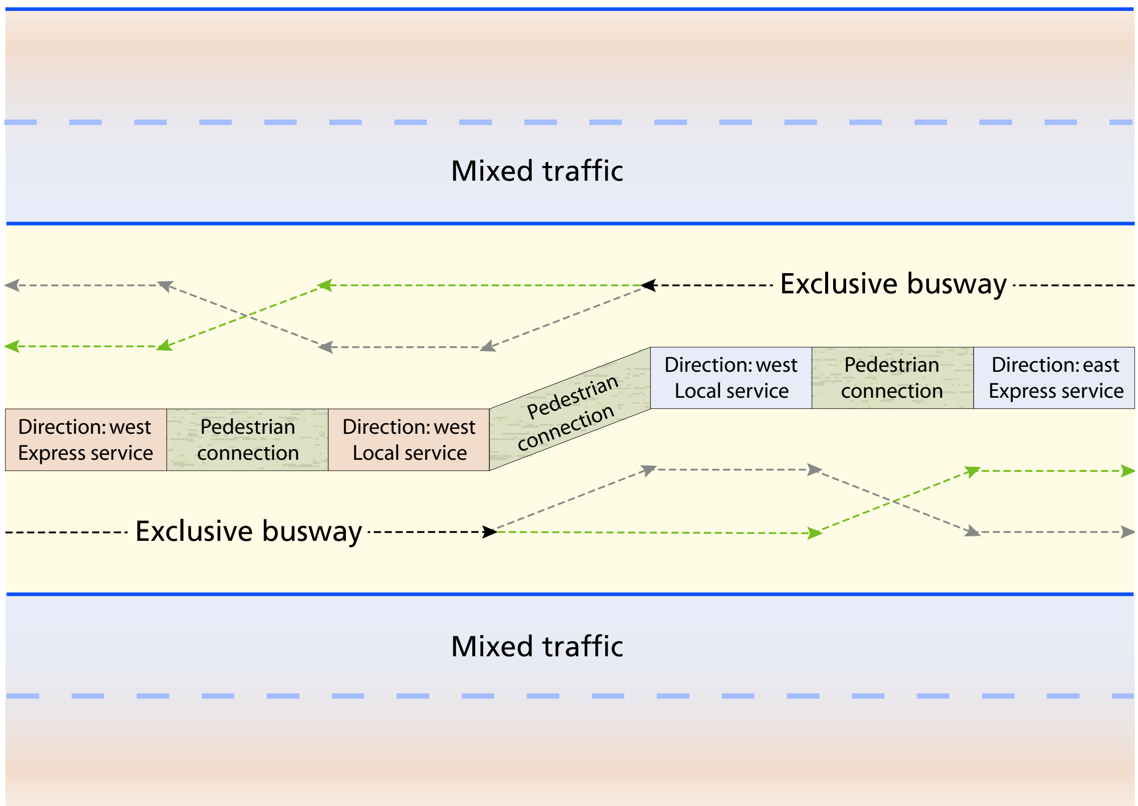


Fig. 11.21
By offsetting the sub-stops and elongating the platform, passing lanes can be fit into relatively narrow road widths.
Design by Lloyd Wright

Fig. 11.22 and 11.23
The colouration of busways in cities such as Nagoya (left photo) and Seoul (right photo) does much to enhance the image and permanence of a BRT system.
Left photo courtesy of the City of Nagoya
Right photo courtesy of the Municipality of Seoul

11.2.4 Colouration of surface

The aesthetic appearance of the lanes will have an impact on the public's image of the system. The colouration of the busway is one option for creating a special and attractive BRT environment (Figures 11.22 and 11.23). A smartly coloured busway not only raises the image of the system but also creates a greater sense of permanence to the existence of the system. Coloured lanes also create a psychological advantage over motorists who may potentially block the busway when the lane must cross mixed traffic. Motorists are more likely to recognise that they are committing a traffic infraction by blocking a highly visible busway, especially when compared to the crossing of a lane that is indistinguishable from a normal mixed-traffic lane.

Colouration of busway lanes can be accomplished by at least two techniques. First, a road surface paint can simply be applied to the busway. The advantage of simply painting the lane is that colouration can be accomplished when just the existing street infrastructure is being converted to a busway. The disadvantage of paint-based techniques is the duration of the colour and the long-term maintenance costs. A second option is to utilise a coloured emulsion within the asphalt or concrete mix. In this case the colouration is a permanent part of the surface material. As the surface begins to wear down, the colour is retained. However, in general, the colour finish of an emulsified coloured surface is less bright than a painted surface. Thus, the aesthetic and marketing impact of an emulsified surface will tend to be inferior to that of a painted surface.

Pigments can be used that produce a luminescent effect. A busway that is luminescent in the evening can be another way of attracting positive attention to the system. In Jakarta the application of a red luminescent paint to the busway gives the system a majestic red carpet appearance in the evenings.

The choice of colour is highly specific to local preferences and local conditions. Local aesthetic values play a role in choosing a colour that will produce a readily identifiable and positive image for the BRT system. Further, a city-wide colour coding scheme should be considered as a mechanism to differentiate between various infrastructure purposes. For example, it might be useful to use a colour for the busway that is different than the colour utilised for the city's cycle ways. In this way, each set of sustainable transport infrastructure has its own unique visual identity. In general, darker colouring shades should be selected over lighter colours. With time tire marks will tend to stain busways

Fig. 11.24
Mechanically guided systems allow greater vehicle velocities and narrower busway width, but these systems to increase construction costs and reduce overall system flexibility.
Photo courtesy of the US Federal Transit Administration

Fig. 11.25 and 11.26
Not paving the centre of the busway can produce infrastructure cost savings as well as reduce operational noise.
Left image (Eugene, USA) courtesy of Lane District Transit
Right photo (Leeds, UK) courtesy of the US Transit Cooperative Research Program

using lighter colours while such wear marks will be less pronounced with darker colours.

11.2.5 Infrastructure for guided busways

A guided busway is a special type of BRT system in which the lateral movement of the bus is controlled by side roller wheels (Figures 11.24). A few guided systems have been developed in cities such as Essen (Germany), Adelaide (Australia), Leeds (UK), Bradford (UK), and Nagoya (Japan). The guidance systems consist of a physical bus track that steers the bus by way of a mounted side roller wheel.

These systems can have a positive effect on speed and safety since the guideway better controls the vehicle's movements. Guided busways also permit a more narrow lane to be constructed, and thus is helpful when road space is limited. However, guided systems are still relatively rare due to their added costs, complexity, and lack of flexibility in use of the vehicles. Table 11.2 summarises the advantages and disadvantages involved with guided systems.

Additionally, since busways do not require the need for vehicle lane changes, some system developers have elected to not pave the centre of the lane (Figures 11.25 and 11.26). The resulting savings in construction costs can be substantial. Further, the existence of earth or grass beneath the bus can help absorb engine

Table 11.2: Advantages and disadvantages of guided busway systems

Advantages	Disadvantages
Higher speeds (reduced travel times) are achievable within safety standards	Increases busway construction costs considerably
Permits construction of narrower busway lanes	Increases vehicle costs
Contributes to a more permanent image of the busway	Reduces flexibility with regard to the type of vehicles that may utilise the busway
Allows construction of lanes without paving the centre strip	Speed advantages of guided busways are only realised when the distances between stations are quite significant

Fig. 11.27
The guideway allows for hands-free driving on the Nagoya Yurikamome Line.
Photo by Lloyd Wright

Fig. 11.28
A stopping device at the end of the guideway ensures that the driver re-engages physical steering.
Photo by Lloyd Wright

Fig. 11.29
An elevated busway in Brisbane allows the system to manoeuvre through a sensitive greenway.
Photo courtesy of Queensland Transport

Fig. 11.30
The Miami People Mover is an elevated system that covers destinations in the city's central district.
Photo by Lloyd Wright

noise; noise reductions of up to 40 percent have been reported using this technique. Not paving the centre of the lane is also an option that other busway developers are considering, even when roller guides are not being utilised. The paved strips for non-guided buses will likely be wider than the strips for guided buses since non-guided buses will be subject to more variation in lateral movement. The feasibility of this approach and cost savings associated with not paving the centre lane area will depend on local construction costs and practices. In some instances, local contractors may not be well-versed in utilising this construction technique. However, given that the paving of the busway represents perhaps the single highest cost item in system infrastructure, any potential cost savings should be considered.

In operating a vehicle along a guided busway, the driver does not actually have to steer the vehicle. The guideways prevent any turning movements, and thus the vehicle can technically be operated "hands-free" (Figure 11.27). In some systems, such as the Nagoya, there are safety concerns at the point the BRT vehicle leaves the guideway. If for some reason the driver does not re-engage physical steering, a mishap may occur. Thus, in the case of Nagoya, a forced stop is made at the exit from the guideway in order to remind the driver to use physical steering once again (Figure 11.28).

11.2.6 Infrastructure for grade separation

Grade separation has already been well discussed in this Guidebook as an option within narrow right-of-way configurations as well as an option at intersections and roundabouts. Grade

Fig. 11.31
A significant number of private vehicles entering the Nagoya busway.
Photo by Lloyd Wright

Fig. 11.32
Motorcycle illegally entering the busway in Pune (India).
Photo by Sujit Patwardhan and the Pune Traffic & Transportation Forum (PTTF)

separation can also be an option to consider to by-pass difficult terrain or water (Figure 11.29). Another common application could be loop lines that must manoeuvre through dense city centres (Figure 11.30).

In all cases, the physical terrain and base materials must be considered for their engineering appropriateness for tunnels or elevated structures. High water tables or hard bedrock can make underpasses and tunnels impractical from a cost and engineering standpoint. Likewise, soft soils can significantly increase the cost of securely siting pillars for elevated structures. Thus, an engineering and cost feasibility analysis should be conducted whenever grade separation is being considered as an option along certain BRT corridor segments.

11.2.7 Restricting access to the runways

The infringement of the busway by private vehicles can do much to harm BRT speeds and overall performance (Figures 11.31 and 11.32). Even just a few vehicles can cause delays to the BRT vehicles. Further, once a few vehicles enter the system, then a breakdown in the appearance of enforcement can lead to mass violations of the exclusive space.

Several mechanisms can be utilised to discourage private vehicle use of the busway:

- Clear signage noting busway use only (Figures 11.33 and 11.34);
- "Busway only" message imprinted upon the surface (Figure 11.35);
- Distinctive colouration of the lanes;
- Median differentiation between the mixed traffic lanes and the busway.

If the busway is separated from the mixed traffic lanes by vegetation or a constructed median, then there is a clearer distinction between the two areas.

Without such measures, there may be instances of inadvertent use of the busway. However, these measures may not be sufficient to deter intentional violations of busway usage. Thus, cooperation with the traffic police in monitoring and enforcing the exclusivity of the busway is also essential.

Fig. 11.33, 11.34, and 11.35
Signage is a basic mechanism to designate an exclusive busway, as seen in these examples from León (top photo) and Jakarta (left photo). Painted information on the busway surface is also an option, as show here form the example in Jakarta (right photo).
Photos by Lloyd Wright

11.2.8 Landscaping

"The smallest patch of green to arrest the monotony of asphalt and concrete is as important to the value of real estate as streets, sewers and convenient shopping."

—James Felt, NYC Planning Commission

BRT systems should add to the aesthetic quality of a city's public space rather than detract from it. All efforts should be made to retain existing green spaces. If the centre median is utilised as the location of the stations, the existing landscape can be left significantly in tact (Figure 11.36). Only the station footprint may require landscape alterations. The other areas can be enhanced with additional plantings (Figure 11.37). Greenery may also be an option as a divider between the BRT system and other traffic lanes.

Trees and plants can also provide climatic protection to pedestrian and bicycle corridors linking with the BRT system. In tropical climates, trees and vegetation can even help partially cover the station structure itself in order to reduce inside temperatures. Likewise, the retention of greenery along a BRT corridor will offset the overall urban heat-island effect which causes urban areas to exhibit heightened tempartures (Figure 11.38).

Some environmental groups in Jakarta expressed concern about the impact of the busway on the trees planted in the median. However, in many respects, the busway will serve as a protective buffer between the mixed traffic lanes and greenery in the median. Prior to the development of the busway, the lane nearest the trees was used for mixed traffic vehicles. Thus, previously the trees were subjected to a constant bombardment from heavy traffic congestion and intense emissions. Now, cleaner public transport vehicles are operating along the corridor at frequencies of every three to five minutes. The busway has therefore calmed the environment around the greenery which should improve the health of the trees.

The development of the BRT system may actually provide an opportunity to create new green spaces in the city. At the same time the busway is constructed, a median can be converted from a dull concrete separator to something dominated by greenery. In the case of BRT tunnels, there can be the opportunity to create new public space. In some instances, the covering of the underpass presents the opportunity for plantings and green space (Figure 11.39).

There is a science to choosing the right plants and trees within the landscape plan. The height of the tree and its eventual branches will have to clear the height of the BRT vehicles. Also, the tree's root structure should grow vertically rather than horizontally. Root structures that grow horizontally beneath the surface will likely cause buckling of the busway materials. Each type of tree has inherent growth characteristics, and thus some research is needed to determine which is most appropriate for the busway environment. The expected life of the tree is also a key factor since it can be quite disruptive to the system to require a new set of trees after only a few decades.

Fig. 11.36
In most cases, the median area along a BRT corridor can remain as green space.
Photo (Kunming) by Lloyd Wright

Fig. 11.37
Plantings along the busway and at stations can do much to improve the aesthetic nature of the area, as show here in an example from Vancouver.
Photo courtesy of the National Bus Rapid Transit Institute (NBRTI)

Fig. 11.38
Busway greenery, as shown in this example from Nagoya, can help to mitigate the urban heat island effect.
Photo by Lloyd Wright

Fig. 11.39
The covering of a new BRT underpass creates new green space along the Central Norte corridor in Quito.
Photo by Lloyd Wright

Local weather conditions will also determine the desirability of whether "deciduous" trees or "coniferous" trees are appropriate. A deciduous tree will shed its leaves during the colder seasons, and thus more heat and sunlight will penetrate to the ground during this period. A deciduous tree is thus part of an effective passive solar strategy for cities which experience both warm and cold seasons. However, one disadvantage of deciduous trees is the possible need to clean fallen leaves from the BRT infrastructure. By contrast, cities without cold seasons may prefer trees that do not shed leaves. These types of trees will provide shade year-round in consistently tropical or warm climates.

Priority should be given to selecting indigenous trees rather than species that are not common to the area. Indigenous species create fewer problems regarding invading species and also typically are more suited to local soil and water conditions.

Fig. 11.40
Without adequate drainage, a heavy storm in Quito puts the operation of the Trolé line at risk.
Photo courtesy of El Comercio

11.2.9 Utilities

The street environment is often far more complicated than the surface would indicate. The street is the principal conduit of many critical city services, including water supply, drainage, sewer lines, and electricity lines. Since BRT systems typically operate on the principal corridors of a city, there is likely to be a concentration of city infrastructure alongside and beneath the busways.

Consultation of city infrastructure maps can determine the extent to which the new BRT system may affect these other services. The construction process must take care as to not disrupt or harm the water and drainage lines. If a new surface material is applied for the BRT lane, then water drainage should be explicitly considered in the design process. Concrete busways and painted busways may be less permeable than the previous surface materials. Worst case storm scenarios should be tested in terms of water build-up. Additionally, solutions for improving drainage on the busways should be such that conditions do not worsen for the mixed traffic lanes.

11.3 Stations

"All architecture is shelter, all great architecture is the design of space that contains, cuddles, exalts, or stimulates the persons in that space."

—Philip Johnson, architect, 1906–2005

BRT stations generally are constituted by three principal elements: 1.) Sub-stops or platforms; 2.) Transition areas; and, 3.) Integration infrastructure such as necessary pedestrian walkways, space for vendors, bike parking, or other commercial activity.

Most sizing aspects of the station and sub-stop design are determined by the operational design. Station functional design and sizing will largely be a function of the projected number of passengers boarding and alighting at any particular station, and the frequency of buses that need to be accommodated at that station. Most of the critical issues of station design have thus already been determined in Part II of this Planning Guide (Operational Design). A few additional sizing issues are detailed in this section.

Beyond the size of a station area, though, there is a host of issues relating to station usability, comfort, and attractiveness. Thus, the aesthetic

Fig. 11.41
At many stations within the Bogotá TransMilenio system, a transition area exists between a single lane busway and two lane configuration for passing.
Photo by Lloyd Wright

form and architectural design of the station area plays a major role in determining the success of the system.

11.3.1 Transition area prior to stations

A busway corridor may change from a single runway lane between stations to two lanes at the station area. The addition of the second lane allows vehicles to pass one another and thus access different station sub-stops. As noted in Chapter 8 (*System capacity and speed*), the ability to operate multiple sub-stops has a highly positive impact on overall system passenger capacity.

In this type of design, a transition zone must exist where the lane configuration changes from a single lane to two lanes (Figure 11.41). This transition area exists both before and after the station area. The length of the transition area must be sufficiently gradual to avoid the necessity for sharp turning movements that will slow BRT travel speeds. The actual length will vary depending on speeds and local conditions. However, in general, approximately 70 metres will be required to expand from a single lane busway to two lanes.

11.3.2 Station platform sizing

The size of the station platform will have an impact on the efficiency with which the station and individual sub-stops operate. The size will also greatly affect passenger comfort. Sizing largely depends on the number of boarding and alighting passengers.

The height of the station is largely a function of aesthetics, although any passive solar extensions to enhance shading must obviously be above the height of the vehicle roof. From the standpoint of waiting passenger crowding, the critical factor is the width of the station.

For an individual sub-stop the length does not contribute greatly to platform capacity since boarding passengers will cluster around the doors waiting to board and exiting passengers disperse quickly. However, the length of the station may be quite relevant if sub-stops for each direction of travel are side-by-side. In cases where the platform width is constrained by the available road width, then staggering the sub-stops along the length of the road can be an effective solution. The staggering of the sub-stops will lengthen the overall station, but it will effectively halve the pressure upon the station width (especially if two vehicles were to stop simultaneously).

The minimum length of the waiting area for passengers (Lp) must be greater than or equal to the length of the BRT bus (Lb). The total length of the platform must also be long enough to accommodate the ticket sales, turnstiles, and other amenities. Generally, adding length to a station is not problematic since the length does not encroach on the right-of-way.

The more sensitive issue is the width of the sub-stop. The platform must be wide enough to comfortably accommodate all projected waiting passengers, provide enough space for passengers to enter and exit the area, and enough space for the infrastructure itself. Equation 11.1 summarises the calculation of the required platform width.

Equation 11.1 Calculation of platform width

$$Wp = 1 + Wu + Wc + Wopp$$

Where:

Wp = Total platform width

1 metre = Width required for infrastructure

Wu = Width required for waiting passengers in one direction

Wc = Width required for circulating passengers

Wopp = Width required for passengers waiting for vehicles going in the other direction

Note that in the case of staggered or offset sub-stops, the value for Wopp will be zero. As indicated previously, staggering the sub-stops will likely double the capacity of a given platform width.

Normally, about 2,000 pedestrians can pass down a metre-wide sidewalk per hour, and still provide a reasonable level of service. Based on this standard, the width required for circulating passengers is given in Equation 11.2.

Equation 11.2 Width required for circulating passengers

$$Wc = Pph / 2{,}000 \text{ passengers per hour}$$

Where:

Pph = Number of circulating passengers expected per hour

The minimum area required for waiting passengers will be a function of the maximum number of passengers projected to queue divided by the capacity of a square meter to hold waiting passengers. Equation 11.3 thus provides the calculation for the minimum area required.

Equation 11.3 Minimum area required for waiting passengers

$$Aw = Qp / DwMax$$

Where:

Aw = Minimum area required for waiting passengers

Op = Maximum number of passengers projected to queue

DwMax = Capacity of a square metre to hold waiting passengers

Box 11.1: Calculation of required platform width

The general equation for this calculation is:

$$Wp \text{ (platform width)} = 1 + Wu + Wc + Wopp$$

In this case, the waiting areas for the two directions are offset, so that "Wopp" is equal to zero. Also, it is assumed that the station infrastructure and curb consume 0.5 metres on each side for a total of 1 metre. Suppose also that the traffic model has determined that the average number of waiting passengers during the peak is 150 (Qp = 150).

The articulated BRT vehicles are typically between 17.8 metres and 18.5 metres long. For simplicity, it will be assumed that $Lp \geq Lb = 18.5$ metres.

To first calculate the total area required, Equation 11.3 will be utilised:

Aw = Qp / DwMax = 150 waiting passengers / 3 passengers per square metre
= 50 square metres

Thus, 50 square meters of platform is required to accommodate the waiting passengers. If the BRT vehicle is 18 metres long:

$Wu = 50 \text{ m}^2 / 18 \text{ m} = 2.8$ metres

The modelling also has projected that 6,000 passengers pass through this popular station every hour. Therefore,

Pph = 6,000 passengers per hour

Based on equation 10.2, the platform width for circulating passengers is:

Wc = 6,000 passengers per hour / 2,000 passengers per hour per metre wide
= 3 metres

Therefore, the total width required is:

Wp = 1 + Wu + Wc + Wopp = 1 m + 2.8 m + 3 m + 0 m
= 6.8 metres

Figure 11.42 provides an illustration of this platform.

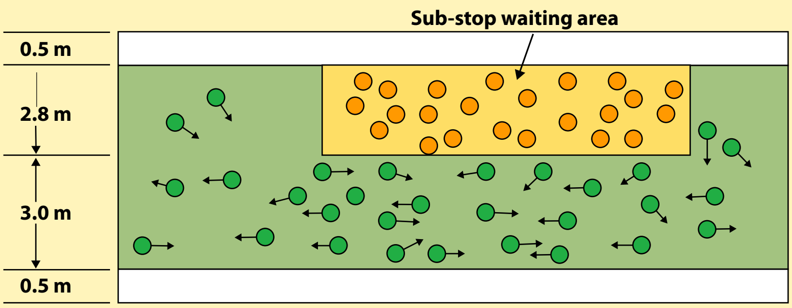


Fig. 11.42 *Result of platform sizing analysis.*

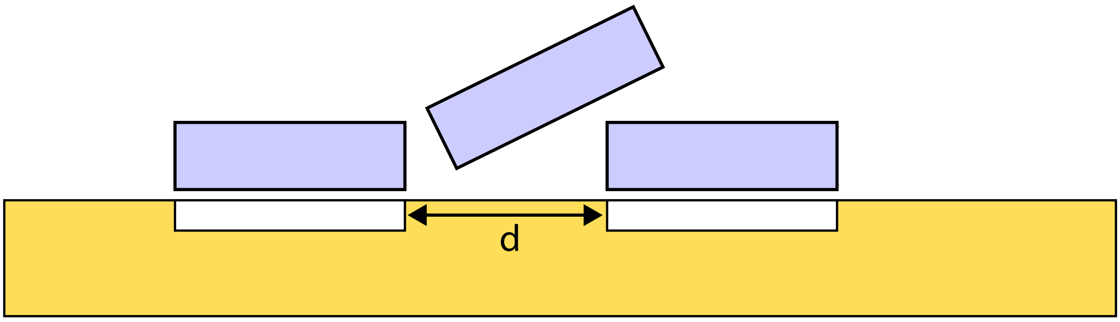


Fig. 11.43
If stopping bays are placed too closely together, then the station area can become congested.
Image courtesy of Pedro Szasz

Normally, waiting passengers are not comfortable if they are constrained to less than a third of a square meter. Therefore, capacity for waiting passengers (DwMax) will be defined as three passengers per square meter, or:

DwMax = 3 passengers per m^2

Some traffic demand models can generate a projected number of waiting passengers at each station based on the origin-destination (OD) matrix. The current number of boarding passengers on bus routes to be incorporated into the BRT system will also be a good guide. If available, this information should be used for the calculation. In the absence of this information, Equation 11.4 provides an estimation of the number of total boarding passengers. Equation 11.4 is used as a safe overestimate of this value.

Equation 11.4 Estimation of total boarding passengers at a sub-stop

$$Qp = \Sigma (PBi/Fi) = \Sigma Pbbi$$

Qp = Maximum passenger queue expected

PBi = Passengers boarding per hour on BRT route i

Fi = Frequency (BRT vehicles / hour) of line i

Pbbi = Average number of passengers boarding per BRT vehicle on line i

Box 11.1 provides a sample calculation for required platform area in conditions with a high-volume of boarding and alighting passengers.

11.3.3 Platform length

For systems with a single stopping bay, the above station sizing determination should be sufficient. For systems with multiple stopping bays, however, additional space has to be included between the sub-stops to accommodate BRT vehicles pulling around one another.

In order for multiple stopping bays to function properly, vehicles must be able to freely enter and exit. If the stopping bays are too closely spaced, then some vehicles may block access to an adjacent stopping bay (Figure 11.43).

In general, the absolute minimum distance required for one vehicle to pass another is one-half the bus length. For example, an 18-metre articulated vehicle requires at least 9 metres of separation between stopping bays. This minimum distance should only be used at stations with fairly low frequency, or where right of way constraint is a significant issue. Normally, BRT systems require more space because:

- Entering and exiting stopping bays with such limited space increases the time it takes to pull into the stopping bay, which reduces speeds and adds to saturation levels.
- If a vehicle using the same stopping bay is directly behind another, the waiting vehicle should be able to wait behind the first vehicle without blocking the stopping bay behind it.

Based upon this criteria, the minimum spacing should be approximately 1.7 times the length of the vehicle. In the case of an 18-metre articulated vehicle, this distance would be approximately 30 metres.

If the vehicle to platform interface does not utilise a boarding bridge, then greater precision is required to align the vehicle to the platform. While a boarding bridge only requires a vehicle to be within 40 centimetres of the platform, the lack of a boarding bridge requires that the vehicle be aligned within 10 centimetres or less. This degree of precision will possibly require a longer approach in order to maintain an effective speed.

Where space permits, room should be left for a second vehicle to wait behind each stopping bay, in order to avoid mutual interference between stopping bays. However, at a certain point, it

Table 11.3: Amount of queuing space required at stopping bays

Saturation level (X)					
From	To	No. of stopping bays	No. of lanes	Amount of queuing space (vehicle lengths)	Total station length (metres)
0.0	0.4	1	1	0	19
0.4	0.7	2	2	1	104
0.7	0.8	2	2	2	142
0.8	1.0	3	2	1	156
1.0	1.4	4	2	1	208
1.4	1.8	5	2	1	260
1.8	2.0	5	2	2	355

Notes:
Total length = (19 m * number of stopping bays) + 33 m
19 m = space for extra vehicle in queue
33 m = 19 m + 14 m (space for stopping bay + overtaking distance)

is more efficient to simply add an additional stopping bay rather than leaving extra queuing space behind each stopping bay. Generally, it is optimal to provide just one queuing space, though in a few exceptional circumstances two queuing spaces are optimal. Table 11.3 outlines the conditions favouring one or two queuing spaces.

As evidenced from the results of Table 11.3, multiple stopping bays do tend to add considerable overall length to a station. This length requirement is particularly acute when additional queuing space is also required. The total length can cause difficulties on corridors with limited longitudinal right of way. Short city blocks may thus constrain the ability to develop stations with multiple stopping bays.

Different stations will have different space requirements. If a particular station hosts a wide number of routes and services, then several additional bays will be needed. Conversely, if the station is just serving a few routes, then possibly only a single bay will be required. Figure 11.44 provides an overview of the different types of stations utilised in phase I of Bogotá's TransMilenio system.

11.3.4 Aesthetic design

"Design in art, is a recognition of the relation between various things, various elements in the creative flux. You can't invent a design. You recognize it, in the fourth dimension. That is, with your blood and your bones, as well as with your eyes."

—D. H. Lawrence, writer, 1885–1930

Architectural considerations are critical to system success from aesthetic, cultural and customer-friendliness perspectives. At the same time, there is no one formula for determining a successful aesthetic design. What is architecturally attractive in one culture may not be attractive in another. In many cases, the architectural design is a matter of "form following function" in which the required physical attributes determined by

Source: TransMilenio, SA

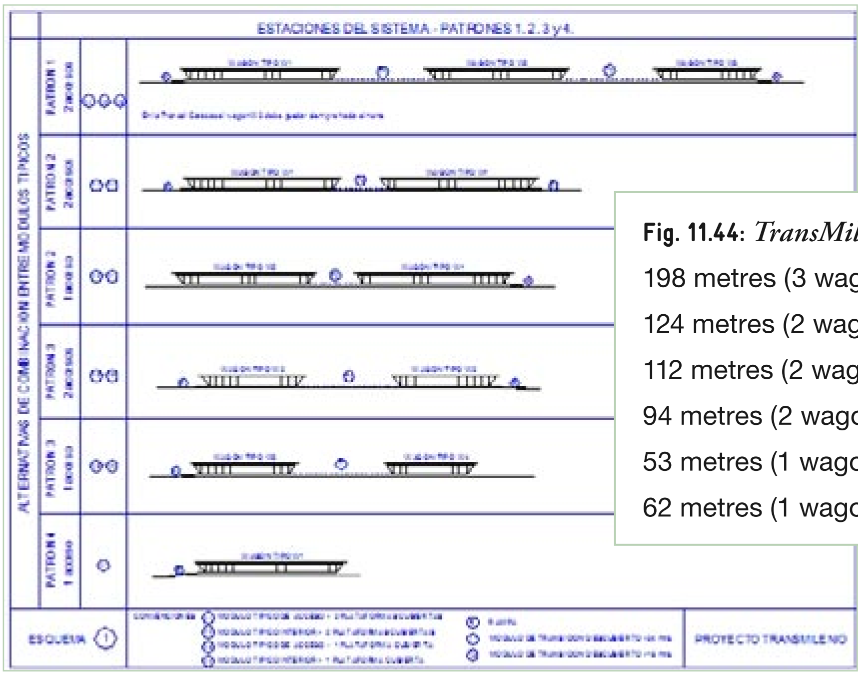


Fig. 11.44: *TransMilenio stations*
198 metres (3 wagons, 5 platforms)
124 metres (2 wagons, 4 platforms)
112 metres (2 wagons, 4 platforms)
94 metres (2 wagons, 2 platforms)
53 metres (1 wagon, 2 platforms)
62 metres (1 wagon, 2 platforms)

the operational plan will greatly influence the design. However, the station aesthetics should be given high consideration since the form and shape of the stations will partly determine customer acceptability. Thus, system planners should request that a range of architectural designs be developed in order to provide a full set of options. Aesthetic design is also not just about the shape of the station but also about other factors such as the colours utilised and the textures of the materials.

It is often desirable to choose an architectural design that reflects the local environment. An indigenous architectural style will ensure that the system is not merely a copy of a form created in another city. Utilising a local architectural style may also influence the extent citizens exude local pride over the system. The stations within the Guayaquil Metrovía system have been designed based upon an architectural style utilised in the city from the 1920s (Figure 11.45). Thus, the Metrovía system provides a connection to the city's history and its surroundings.

Many systems opt for a highly modernised appearance, which helps to position BRT as a new class of public transport. Modern designs can conjure up customer impressions of sophistication, style, and speed. The tube structures in Curitiba have become an international symbol of BRT as well as provide customers with an image representing speed and modernity (Figure 11.46). The genesis of the tube design was in many ways to replicate the positive image of metro systems and their underground image of tubes whisking customers from one part of the city to another.

Fig. 11.45
Guayaquil utilises an architectural style relating to the city's history.
Photo by Carlos González

While the Curitiba tubes have been quite successful in creating an iconic image for the city, there are a few limitations to this type of design which could restrict its use elsewhere. First, the rounded design can be a limitation of system

Fig. 11.46
The modern tubed stations in Curitiba have created an iconic identity for the city.
Photo courtesy of URBS and the Municipality of Curitiba

Fig. 11.47 and 11.48
Clean and simple design in Brisbane gives the system a look of modernity and sophistication.
Photos courtesy of Queensland Transport

Fig. 11.49
In the city's historical centre, Quito made its stations less obtrusive in order to be more congruent with the architectural surroundings.
Photo by Lloyd Wright

capacity. The circumference of the tube is limited by the required proximity between the station and the vehicle. A larger circumference will tend to push the nearness of the vehicle too far from the station floor. Second, the tubes can also act to create a mini-greenhouse effect in which heat is entrapped and thus making interior conditions uncomfortable for customers. However, louvered openings could be employed on tube stations which would allow for better airflow.

Modern architectural styles often deliver relatively "clean" look within a sort of minimalistic framework (Figures 11.47 and 11.48). The station designs in Brisbane epitomise this type of approach. The excellence of the Brisbane design has in fact resulted in the designers receiving various architectural awards. Likewise, stations in cities such as Las Vegas and Rouen have likewise utilised simple, clean designs to evoke a modern appearance.

Roof lines based on a "wave" design can also produce a highly modern perspective. The initial designs in Dar es Salaam and Johannesburg have made use of such a design appearance.

However, the modern look may not always be appropriate. If the system runs through or along corridors of great historical value, designers may wish to seek congruence with the adjoining architecture. Congruence with the surroundings was the reason that Quito re-designed some of its Trolé line stations in the city's historical centre (Figure 11.49). It was felt that the enclosed stations were visually too forceful within the historical centre, which is listed as a UNESCO World Heritage Site. Thus, the city opted for a more open design for the station at the Santo Domingo plaza. However, one negative aspect of such open-sided designs is that it makes passengers more exposed to wind and rain.

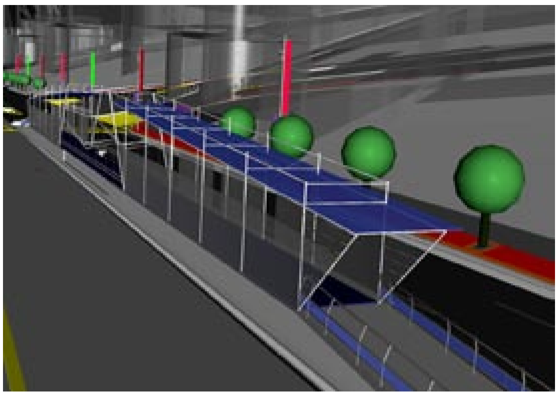


Fig. 11.50 and 11.51
An architect's vision may not be reflected in the implemented product due to the choice of materials and construction options, as demonstrated by this pre-project rendering and the resulting product along the Quito Central Norte line.
Left image courtesy of the Municipality of Quito
Right photo by Lloyd Wright

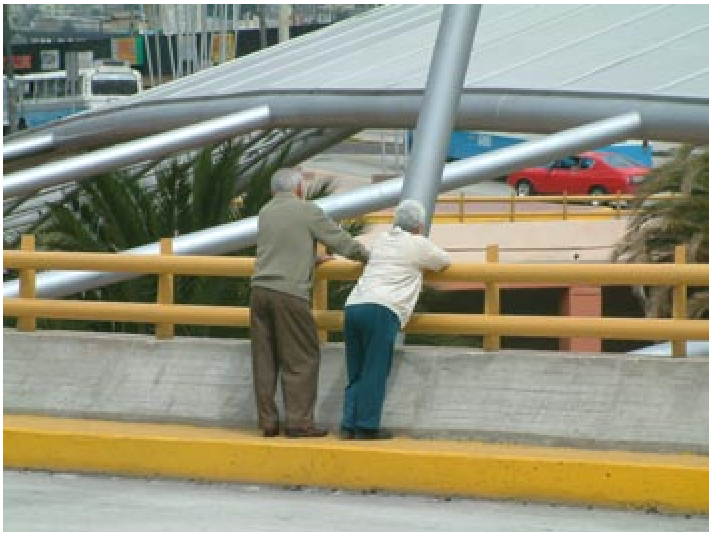


Fig. 11.52 and 11.53
With an array of aesthetic attractions, the Villa Flor station in Quito actually draws persons who just come to observe the system.
Photos by Lloyd Wright

The design's form, of course, is only part of the process in delivering a station of a particular style. The right combination of colours and textures can also affect the customer's perception of a station's aesthetics. The congruence of the chosen materials with local conditions, such as durability in local weather conditions, also plays a role. The premature rusting of stations in Quito may be due to both a lack of appropriate maintenance as well as the rainy conditions that exist for much of the year. Implementation choices also determine if the architect's vision is represented in the final product. The pre-project renderings of the stations for Quito's Central Norte line gave the impression of a high-quality and modern system (Figure 11.50). The reality of implementation and the chosen materials produced a somewhat less impressive result (Figure 11.51).

Station aesthetics can be negatively affected by over-use of advertisement displays. While advertising may be a needed source of revenue, too much advertising will detract from the visual clarity of the system and can lead to customer confusion, especially when system maps and other key information displays are difficult to find due to visual clutter. Thus, any decision to permit moderate amounts of advertising must be taken in conjunction with aesthetic and functional considerations.

The ultimate test of any architectural design is the public's opinion and usage of the infrastructure. A well-designed station is not only an entry point into a public transport system but also an intimate part of the urban fabric and a potential focus of community pride. The Villa Flor station along the Quito Trolé line boasts an assortment of design interests apart from its functioning as a public transport station (Figure 11.52). The array of greenery and waterfalls actually draws crowds of persons who come just to observe the station area (Figure 11.53). In such cases, system designers may even wish to construct observatory points to allow residents to enjoy the system environs in the same way observation decks are utilised at airports.

11.3.5 Climate Control

"Climate is what we expect, weather is what we get."

—Mark Twain, author, 1835–1910

Protection from weather is a major consideration in station design. The image of the station as a refuge from the outside world can help attract customers. In many developing-nation cities, high temperatures and humidity are a concern. Open designs can also be an option, especially in warm locations. More open designs, though, do increase the need for protection against fare evasion. However, the example in Figure 11.54 shows that it is possible to achieve both an open design and relatively good natural deterrents to fare evasion.

The viability of an open design will depend on the variability of seasonal weather patterns. An open design may provide refreshing comfort during summer months, but such a design may also expose customers to wind, rain, and cold during winter periods. In cities with highly variable climatic conditions, a flexible design may be possible where louvers and foldable sides

Fig. 11.54
A station design can provide both openness to encourage good air flow as well as protection against fare evasion.
Image courtesy of the Municipality of Pereira

allow station managers to adjust the station configuration according to the conditions.

Air conditioning systems and ventilator fans are options to consider, especially in hot and humid conditions. The use of air conditioning in both stations and vehicles can contribute greatly to the desirability of the system, especially with respect to capturing customers who were previously private vehicle users. Air conditioning in tropical climates can contribute to the image of the public transport system as a city oasis. However, the use of air conditioning units brings with it cost and technical considerations. With air conditioning, sliding doors must be utilised both at the entrance to the station as well as at the interface between the platform and the vehicle doorways.

Fig. 11.55
A refuge area within a station can provide an air conditioned and/or heated waiting environment at a fraction of the cost of controlling conditions along the entire station, as shown in this example from the Osaka Monorail.
Photo by Hiroto Inoi

The amount of time these doorways must be open will determine the viability of controlling the interior temperature with air conditioning. At high-volume stations, the amount of time the doorways must be open can make the sizing of the air conditioning system unrealistically costly. Further, a high use of electricity at the station can undermine the overall environmental performance of the system.

As an alternative to fully air conditioning (or heating) the entire station area, an enclosed refuge area can be built inside the station. Customers wishing to access a climate-controlled environment can open the door and enter the refuge area. Rail stations in Japan make particular use of refuge areas that provide air conditioning during the summer months and heating during the winter months (Figure 11.55).

Another lower cost alternative to full air conditioning can be fans and mist generators. These systems provide customers with a refreshing mist of cool water to reduce the discomfort of high temperatures (Figures 11.56 and 11.57). These systems also offer the advantage of allowing customers to choose their own comfort level by opting to stand near the device or not.

Passive solar design and natural design techniques offer the advantage of mitigating temperature extremes without the need for costly external energy inputs. Passive designs use shading and natural air flows to provide

Fig. 11.56 and 11.57

Mist generators and ventilator fans are a cost-effective alternative to air conditioning as shown in these examples from the Pattaya (Thailand) bus terminal (left photo) and along a street in Kuala Lumpur (right photo).

Left photo by Carlos F. Pardo
Right photo by Lloyd Wright

relief to customers (Figure 11.58). For example, an overhang from the roof line can do much to shield the station platform from direct sun. In some cases, the same overhang can fold down to help close the station during non-operating hours. Also, as noted above, louvers in the station wall can encourage refreshing air flow across the platform area.

Vegetation above the station, either from planted trees or a green lattice, can also be an effective and attractive climate control option. Such vegetation can do much to mitigate the "heat-island effect" in which structural materials (such as concrete, asphalt, and metal) radiates and intensifies heat in the local area. Instead, trees and plants act to absorb heat and reduce the impact on waiting customers.

While quite positive in terms of temperature moderation, passive design options should not detract from the aesthetic quality of the system. The curved overhangs on the Leon (Mexico) system are helpful in terms of climate control but have been criticised for aesthetic reasons (Figure 11.59). Thus, the functional design of a station area should be complementary and not detract from the aesthetic design.

Systems in cities with cold climates may also wish to consider climate control options. Heated station areas and heated vehicles will likewise create an image of the public transport system as a refuge from a hostile environment.

11.3.6 Platform doorways

The station to vehicle interface is the point at which a closed station is sometimes vulnerable to fare evasion. If left open, the platform doorways can be , even with high-floor stations (Figure 11.60). The station portals opening to the vehicle and the road are also points where

Fig. 11.58

Passive solar design provides shading and encourages natural air flows without the need for costly air conditioning systems.

Image courtesy of the Municipality of Barranquilla (Colombia)

Fig. 11.59

While this roof overhang in León provides shading to passengers along the platform, many consider it to be aesthetically unappealing.

Photo by Lloyd Wright

Fig. 11.60
Without sliding doorways, customers may evade fare payment and endanger their safety by entering and exiting through the platform doorway.
Photo by Lloyd Wright

inclement weather can enter and affect passenger comfort. Further, this interface can also represent a safety hazard since passengers falling to the roadway can be seriously injured.

For all these reasons, a doorway that only opens upon the arrival of a vehicle can provide benefits to both the system and the customer. Sliding doors are used on various mass transit systems, including the BRT system in Bogotá and Quito. In addition to protecting the customer and preventing the entry of fare evaders, the sliding doors also create a higher sense of system professionalism (Figures 11.61 and 11.62).

The disadvantages to the sliding stations doors relate to cost issues. The initial infrastructure cost addition is relatively small to the overall cost of the station. Likewise, the on-going electricity costs for operating the doorway are also relatively small. However, sliding doors do carry with it concerns affecting maintenance costs and system reliability. From experiences in cities such as Bogotá, the sliding doors are one of the most common system components to fail, albeit on a temporary basis. In the case of a breakdown, the doorways can be placed in the open position so as to not interfere with system operation. However, an open station doorway can create significant opportunity for fare evasion. Thus, the robustness of the sliding door technology as well as the availability of rapid-response repair teams are factors to consider in developing both the operational and infrastructure plans.

11.3.7 Station identification signage

The identification of a station's location from a distance can be useful in attracting patronage. Iconic signage that allows the customer to immediately identify the system can be an important element of the wider marketing effort. To extent, maps and signposts along footpaths can be helpful (Figure 11.63), but the immediacy of a station signage post provides a quick visual image to focus customer attention. The station signage posts can be quite useful to customers located between two stations. The posts allow such customers to quickly determine which station is the closest to them.

The height of the signage post will be a principal factor in creating a sight line that is visible from a great distance. However, the height of the signage post will be limited due to cost and local zoning restrictions. The colour and letter

Fig. 11.61 and 11.62
Sliding station doors serve several functions including customer safety, climate control, and fare evasion.
Top photo by Carlos F. Pardo
Bottom photo by Lloyd Wright

Fig. 11.63
System signage near station areas can be useful in pointing customers in the right direction as this example from Orlando shows.
Photo by Lloyd Wright

Fig. 11.64
The colour, shape, and form of this station sign post in Brisbane allows customers to quickly recognise the presence of a station.
Photo courtesy of Queensland Transport

size on the post will also determine recognition levels (Figure 11.64). Typically, the name and logo of the system will be prominently displayed on the sign post along with the name of the particular station.

An image related to the particular station may also be displayed on the sign post. Such visual imagery helps passengers to quickly recognise their destination. The name of a hospital, university, or zoo may not mean anything to some passengers (especially occasional visitors), and thus a representative drawing may provide more immediate recognition (Figures 11.65 and 11.66).

The sign post may also include other pertinent information. For example, in Bogotá each sign post also includes a clock (Figure 11.67). However, at the same time, designers must avoid placing too much information on the posts. Visual clutter will reduce the overall objective of allowing customers to quickly recognise a station's location.

Fig. 11.65 and 11.66
In Quito, station sign posts reflect the local character of the station area. The image of children on the sign post (left photo) indicates that the Baca Ortiz children's hospital is located near this station. The stadium station sign post (right photo) is represented by a stadium image.
Photos by Lloyd Wright

Fig. 11.67
Station sign posts in Bogotá include the system name and logo, the name of the particular station, and a clock.
Photo by Lloyd Wright

11.3.8 Electrical supply

Stations, terminals, and depots require electrical energy in order to power a range of supporting infrastructure, including lighting, fare collection and fare verification equipment, automatic station doors, and climate control. The normal method is to supply the bus stop with power directly from the power grid. However, in some countries power from the grid is unreliable. In systems where the fare collection and verification system relies on a supply of electric power, a power failure can cause major problems in terms of the security and integrity of the fare collection system. In such cases, reliance on electric power at the station should be minimised to the greatest extent possible, or back up power generation systems should be included in the physical design from the beginning.

The median location of many BRT stations may make connections with electric power lines unsightly, and ideally they should be buried. Additionally, systems seeking to further boost their environmental credentials may wish to procure electricity from sustainable sources.

Against this backdrop, in higher income countries, solar energy systems are increasingly being viewed as a viable electricity supplier for bus shelters and stations. Solar photovoltaic panels (PV panels) generate electricity as photons from the sun strike the substrate material on the panel. As the market for PV panels has grown over the past decade, generation costs have dropped to reasonably competitive levels, especially in circumstances where the construction of costly transmission lines can be avoided. Electricity generated from PV panels produces no air emissions of any kind.

In 2005, Transport for London (TfL) completed a successful three-year evaluation of solar energy systems at 200 London bus shelters (Figure 11.68). As a result of this trial, London is now in the process of converting all 7,000 shelters in the city to solar PV panels. In Naples (Italy), three terminals currently make use of PV panels (Figure 11.69). The Naples system will produce approximately 5 million kWh during its expected 30-year lifespan (Allen, 2005).

11.3.9 Amenities

System designers also face decisions regarding the types of additional services that may be offered within a station. Amenity options for customer service have been discussed in Chapter 10 (*Customer service*). The provision of video, audio, seating, restrooms, security cameras, etc. involves decisions about costs and local preferences. Once the decision has been made

Fig. 11.68 and 11.69
Photovoltaic (PV) panels are an environmentally sustainable manner to service station and terminal electricity needs.
Left photo courtesy of Transport for London (TfL)
Right photo courtesy of UITP

Fig. 11.70
Comfortable seating in a park-like setting enhances the customer experience at a Bogotá TransMilenio station.
Photo by Lloyd Wright

to include such amenity items, infrastructure design issues over colours, textures, materials, and location will arise. The addition of such amenity infrastructure should be done in a manner that is consistent with the other elements of the station.

The provision of seating at stations and terminals can help relieve tired bodies during the waiting period. The options for customer resting include formal benches as well as customer leaning posts (Figures 11.70, 11.71, and 11.72). Formal benches can sometimes be problematic if certain customers choose to lie down upon it, and subsequently pass long periods there without the intent to actually travel on the system. Thus, some systems, such as the Bogotá TransMilenio system, have purposely chosen not to provide seating for customers within many of its stations. TransMilenio also believes that its short wait times (usually less than three minutes) void the need for station seating (Figure 11.73). For systems with longer headways and thus longer wait times, some form of resting infrastructure may be considered. However, the placement of resting infrastructure should be done such that it does not conflict with doorway locations or cause congested customer movements during the boarding and alighting process.

Fig. 11.71
Seating post as provided at a station in the Kunming BRT system.
Photo by Lloyd Wright

11.3.10 Commercial space

Public transport stations are more than boarding-alighting platforms for travel. They are urban public spaces, which have an architecturally defined space and aesthetics, where people meet and socialise or sit alone and wait to board the public transport vehicle. And like all in public spaces in the city, when people meet or wait, a variety of activities are undertaken, including shopping, eating, relaxing, and socialising. The availability of shops and vendors provides convenience to commuters who can combine travel with other value-added activities and chores. Some of the most common types of requested services include:

- Water, food and snacks;

Fig. 11.72
A leaning post can be an economical way of providing comfort to waiting passengers.
Photo by Lloyd Wright

Fig. 11.73
With high passenger flows and short headways between vehicles, TransMilenio has elected not to utilise seating in most of its stations.
Photo by Carlos F. Pardo

- General grocery products;
- Bakery goods;
- Pharmaceutical products;
- Clothing;
- Telecommunications services (telephone, internet, etc.);
- Shoe repair, key making;
- Bicycle repair.

In many cultures, it may be quite common to have tea, snacks, or juice prior to departing on a journey, or it may be common to enjoy such treats upon arrival at a destination.

Public transport stations also represent great value from the perspective of vendors and shop owners. The high volume of public transport customers through stations and terminals provides vendors with a concentration of potential clientele. The value of commercial property near stations often is representative of the high value merchants place upon potential customer volumes.

The needs of the commuters are met both by the services provided by the street vendors and the formal establishments like kiosks, shops, and large commercial centres. Given the variety of customer needs, each type of commercial establishment meets a certain market demand. Services provided by vendors are often less expensive because of low overhead costs and are also less time consuming to access. Therefore, commuters who are sensitive to out-of-pocket expenses, and are in a hurry, patronise these vendors. On the other hand, some commuters may have product needs that can only be met at larger retail facilities. It is important then to understand the roles of both types of commercial spaces in the public transport system, their utility, their economics, their constraints and how they can be integrated in the design of the public transport stations.

Commercial spaces at public transport stations, whether planned or unplanned, answer the needs of the commuters. They work on the market model of demand and supply and are guided by the number of passengers, average wait time, average bus-trip distance etc. Therefore it is necessary to understand the exact nature of the demand for commercial spaces before planning for them. The integration of commercial exchange with public transport operations is another form of providing convenience and service to the customer. This section refers to the importance and planning process of integrating commercial spaces with BRT stations.

11.3.10.1 Street vendors

Benefits of vendor activity

In many cultures, street vendors are an indispensable part of daily life. Such merchants provide an array of services at minimal cost. A detailed study (Tinker, 1997) of vendors selling food on the streets of seven cities in Asia and Africa documents the important role these vendors play in a city. It found that street foods are frequently less expensive than home-prepared foods, especially when time spent shopping and cooking is factored in. Lower-income groups may spend 50 percent to 80 percent of the household budget on food, and thus money saved in this regard can be significant.

At the same time, the street vendors come from the lowest socio-economic strata of the city, finding livelihood in informal service provision. And hence, the employment in the street-vending sector is the means of survival for a large section of the urban poor. According to Tiwari (2000), the availability of work options on the street provides a positive outlet for employment and earning an honest livelihood to a large section of the population that is poor but with high entrepreneurial skills.

Apart from the economic contributions of the street vendors at public transport stations, they also contribute socially to the public transport system. Jacobs (1961) first coined the metaphor of "eyes on the street" while referring safety on the streets due to the presence of vendors. There

Fig. 11.74
Small-scale vendors in Dar es Salaam take over a lay-by area originally intended for mini-bus taxis.
Photo by Lloyd Wright

is now a variety of literature that supports the theory that the presence of street vendors in Asian cities is a prime reason for the low street crime witnessed there.

Problems of unplanned vendor activity

However, the provision of infrastructure for commercial activities within or near public transport stations can also be a source of controversy. Some public transport agencies may not view commercial activities as being consistent with the objective of encouraging rapid customer movements. If left uncontrolled or unplanned, vendors may tend to block walkways, and thus inhibit access to stations (Figure 11.74). Aggressive sales techniques may also make some public transport customers uncomfortable with using the system. Further, waste and debris left behind by vendors can lead to an aesthetic deterioration of the station environment.

Some systems, such as TransMilenio in Bogotá, have largely prohibited vendor activity near stations in order to avoid these types of problems. Most public transport agencies also prohibit open food and drink containers inside the BRT system. The cost of cleaning spilled items and the impacts on the longevity of infrastructure components frequently justify this type of restriction.

Designing for vendor integration

However, in many cultures, the employment and social justice impacts of vendor displacement is a highly sensitive matter. Simply evicting these individuals will have traumatic impacts on the individual, their families, and

Fig. 11.75
In cities such as Delhi, vendor activity near public transport stops provide important employment opportunities.
Photo courtesy of iStockphoto

society at large. Further, in cultures of South and Southeast Asia, the services provided by the vendors are intricately woven into daily life (Figure 11.75).

In Delhi (India), the BRT development team are implementing a novel approach of formal vendor integration into the infrastructure design process. By providing vendors with a formal space near the station, all sides can win. The higher quality space provided to the vendors can in fact improve their work conditions and their care of the public transport environment. Further, the formal inclusion of vendor space in the design process can ensure these sites do not conflict with passenger movements.

Prior to the commencement of design activities on the Delhi BRT system, the development team conducted a customer needs assessment (Figure 11.76). This assessment included a survey of the hawkers and the vendors associated with the existing bus-stops on the corridors. The survey showed that "the intensity and nature of commercial activity generated at a bus-stop is directly proportional to the rate of flow of passengers which is represented by the arrival rate of buses. The study concludes that if the bus arrival rate is less than 2 every 30 seconds, no separate infrastructure needs to be provided for the vendors. At locations where the bus arrival rate is 2 or more, space between 2 adjacent bus-shelters can be developed for vendors" (Gandhi, 2002).

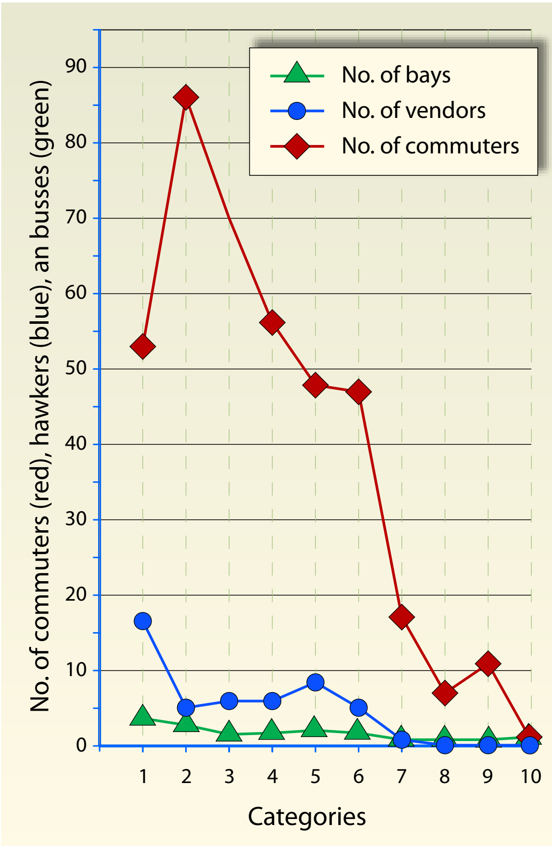


Fig. 11.76
Relationship between, vendor demand, bus bay requirements and commuter volumes.
(Source: Gandhi, 2002)

The survey also showed the great customer demand for vendor activity in conjunction with public transport services. Approximately 96 percent of the commuters surveyed had used the services provided by the street vendors. A majority of the vendors (77 percent) occupy spaces between 1 and 2 square metres near the bus stops. Approximately 70 percent of the hawkers earn less than US$2 per day, and thus again indicating the significant socio-economic benefits of integrating vendors with system design.

A few bus shelters in Delhi have been designed with spaces for vendors as an integral part of their bus shelter design. The amount of area given to the vendors is decided on the basis of passenger volume counts and frequency of buses and integrating them in design ensures that while the vendors provide the requisite conveniences to the public transport commuters, they do not interfere with passenger and vehicle flow.

In some instances, there may be insufficient space in the median to accommodate vendor activity. However, the Delhi development team has resolved this problem by providing vendor spaces along the curb-side. In these cases, great care is taken to ensure that adequate space also remains for comfortable pedestrian movement alongside the vendor stalls (Figures 11.77 and 11.78).

In many cultures, the presence of vendors at public transport stations is an inevitable necessity, especially in locations where passenger volumes are high. The importance of vendors is especially the case in South and Southeast Asia. In such instances, the banning of vendors may in turn encourage undesirable side-effects, such as the bribing of security personnel and the invasion of vendors into unanticipated areas. Instead, the appropriate consideration of vendor space within station design and layout can produce a winning situation for the public transport agency, the vendor, and the public transport customer.

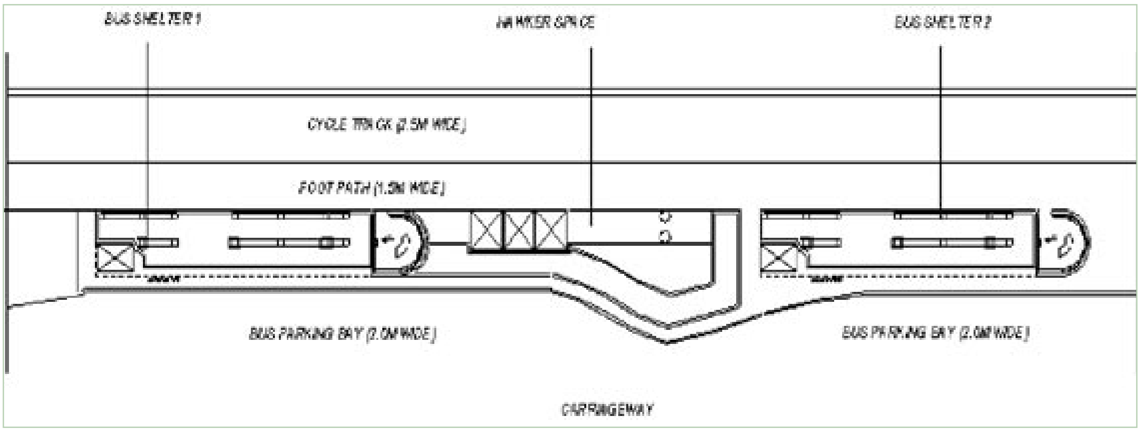


Fig. 11.77
Schematic of bus shelter with integrated space for vendor activity.
Image courtesy of the Indian Institute of Technology–Delhi

11.3.10.2 Larger commercial sites

Public transport stations may also attract the attention of large commercial retailers seeking to reap the benefits of passenger flows. Likewise, the ability to conduct grocery shopping and other tasks near the public transport corridor is a benefit to customers. The presence of these commercial entities also offers some opportunities for financing the station and terminal construction costs. Chapter 17 (*Financing*) provides more detail on this topic.

From an infrastructure standpoint, it is possible to integrate commercial enterprises into the station and/or terminal sites. The availability of space is the prime determinant along with the ability to design the shop to avoid conflicts with passenger movements. The Bangkok SkyTrain system hosts small shops within its elevated concourse. If a BRT system has an underground tunnel connecting interchange stations, then an underground shop location could be feasible. Terminals perhaps offer the greatest potential since space is typically more readily available. Terminal sites often also reduce the distance goods must be carried home.

Commercial enterprises can also benefit by locating near the station and terminal locations without actually being within the public transport property. In Bogotá, large commercial centres have opened near the TransMilenio corridor (Figure 11.79). Capturing the value added to these property developments and applying the added value to system financing is a subject of much interest. More information on land

Fig. 11.78
Complete bus shelter with integrated vendor space.
Photo by Lloyd Wright

Fig. 11.79
In Bogotá, many large commercial centres have opened alongside the TransMilenio corridors.
Photo by Lloyd Wright

benefit levies (LBL) can be found in Chapter 17 (*Financing*).

However, as noted previously, retail integration with the public transport system brings with it unintended complications. The presence of shops within the system adds a layer of complexity to passenger flows and can slow customer throughput. Some of the issues to be considered in retail integration include:

- The retail activity not being related to commuter movement and encouraging inflow of non-users to the station, thus inconveniencing the users and reducing efficiency of the station;
- Induced traffic and parking demand from non-users of the public transport station can put unanticipated load on parking areas and access roads leading to congestion around the stations and making the system unattractive to commuters;
- Retailing employees are typically given free access to the shops, but such exemptions can spiral into abuse of system entry;
- Finally, deliveries to shops can also create congestion if not carefully controlled or relegated to non-operating hours.

11.4 Transfer stations, terminals, and depots

"Design is directed toward human beings. To design is to solve human problems by identifying them and executing the best solution."

—Ivan Chermayeff, architect, 1900–1996

Facilitating easy and efficient customer movements directly affects travel times, convenience, and ultimately customer satisfaction. In many BRT systems, transfer facilities provide the means to cost-effectively combine different types of services, such as feeder services and multiple trunk-line services. Thus, "intermediate transfer stations", "interchange stations", and "terminals" all serve to facilitate ease in customer movements between different routing services.

"Depots" and other BRT vehicle parking facilities do not directly affect customer transfer convenience, but the location, layout, and management of these facilities will affect overall system efficiency.

Each of the infrastructure elements that will be described in more detail in this section are defined as follows:

1. *Intermediate transfer stations*
   Facility that permits transfers between feeder services and trunk-line services.
2. *Interchange stations*
   Facility that permits transfers between different trunk-line routes.
3. *Terminals*
   Large facility typically located at the end of a trunk-line corridor that allows transfers between multiple feeder services.
4. *Depots*
   Facility that serves multiple system tasks including fleet parking, vehicle refuelling, vehicle washing, vehicle service and repair, employee services, and administrative support for operators.
5. *Intermediate parking facilities*
   Facility that allows BRT vehicle parking at intermediate locations along the corridors.

Figure 11.80 illustrates how each of these infrastructure elements can come together within an actual system.

Not all of the facilities discussed in this section may be necessary in a given BRT system. The usefulness of these infrastructure elements depend much upon the local circumstances. Systems employing "direct services" will likely not utilise either intermediate transfer stations or terminals. Instead, vehicles operating in a direct services system will proceed directly from trunk corridors into lower-density areas. Systems with direct services, though, may still utilise interchange stations where transfers between different trunk routes are facilitated.

One key difference between BRT systems and conventional bus systems is the nature of the transfer between different routes and services. Within a BRT system, all trip service and routing options are integrated both in terms of fare structure and physical proximity. It is the ease of transfers and the multiple travel options that sets BRT apart from conventional services.

The number and type of transfer facilities will depend largely on the operational plan that was articulated in Part II of this Planning Guide. The operational plan will have determined several key factors, including the number of BRT vehicles, the number of corridors, and the number of trunk and feeder routes converging upon a site. Likewise, local physical factors, such as available right-of-way, will in part determine the location of transfer facilities.

11.4.1 Intermediate transfer stations

Feeder connections to the trunk lines do not necessarily occur only at major terminal facilities. Feeders can also intersect the trunk corridors at what are known as intermediate transfer stations. These stations are somewhat a hybrid facility between ordinary local stations and terminal facilities. Figure 11.81 provides an overview of the relationship between standard stations, intermediate stations, and terminal facilities. As noted above, systems with direct services generally avoid the need for intermediate transfer stations.

Unlike terminal sites, intermediate transfer stations may not have the luxury of space to easily accommodate both feeder platforms and trunk-line platforms. Thus, a bit of creativity is required to design and control the transfer process.

The options for facilitating transfers can be divided into "open transfers" and "closed transfers". As the name implies, an open transfer takes place in an open environment in which it is not necessary to physically combine the feeder and trunk sub-stops into an enclosed environment. By contrast, a closed transfer takes place in a fare-controlled environment in which one is either inside the system or outside the system.

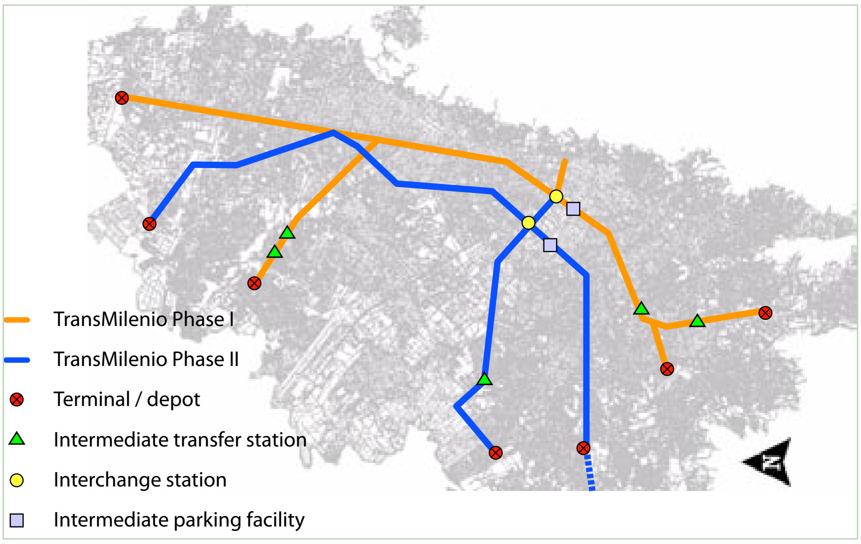


Fig. 11.80
Transfer stations, terminals, depots, and vehicle parking facilities for Bogotá's TransMilenio.

11.4.1.1 Open transfers

For open transfers, there are several different options available. The simplest is perhaps the free fare option in which no fare is required to enter the system. Customers are able to transfer from one service to another without worrying about whether they are in a paid or unpaid zone. Systems such as the Orlando LYNX Lymmo and the Eugene EmX do not charge a fare, and thus, such systems have considerable flexibility with infrastructure and transfers. Of course, free fare options invoke other issues such as operational subsidies, which are discussed in Chapter 16 (*Operational costs and fares*).

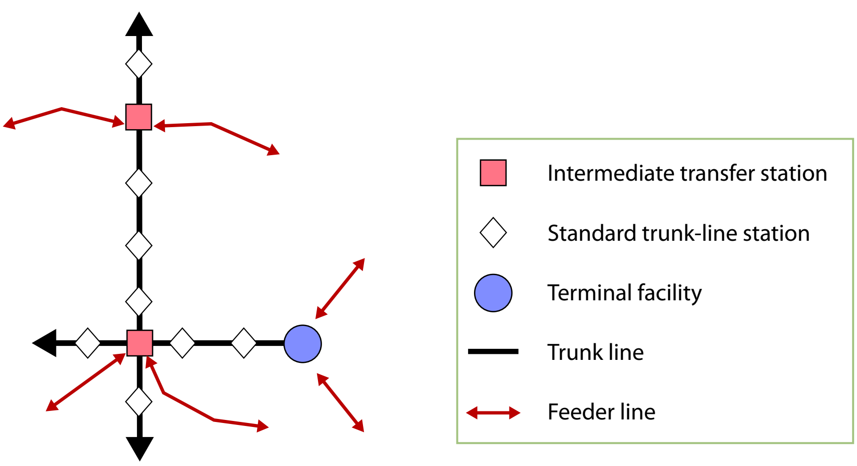


Fig. 11.81
Schematic illustrating the difference between a terminal facility and intermediate transfer stations.

Fig. 11.82 and 11.83
Customers arriving by the green feeder vehicles in Bogotá transfer over a pedestrian bridge to enter the trunk service.
Photos courtesy of TransMilenio SA

Bogotá has utilised a form of the free fare approach by restricting fares only to the trunk service. Thus, customers utilising the feeder services do not pay a fare upon entering the feeder vehicle. Instead, customers only paid a fare once arriving at a terminal or at an intermediate transfer station. In the terminals there are clearly defined paid and unpaid zones which are separated by physical barriers. Likewise, at the intermediate transfer stations, customers must verify fare payment when entering the trunk line portion of the station area. In most cases, the feeder service has a stop nearby the trunk station and customers access the trunk station by way of pedestrian bridge (Figures 11.82 and 11.83). To date the TransMilenio system includes five intermediate transfer stations of this type.

At some intermediate transfer stations in Bogotá, such as the Banderas station, the interconnection between trunk and feeder services is quite elaborate (Figure 11.84). Customers cross between the two areas in a completely weather-protected environment (Figure 11.85).

The feeder area involves multiple stopping bays offering a variety of feeder route destinations.

The provision of free feeder services in Bogotá has created its own problems due to some customers not utilising the trunk services upon arrival. A percentage of the customers are only using the feeder services and are thus not providing any income to the system. Since the operators have a financial interest in preventing this type of "free rider", some policing of feeder customers does take place. However, to combat this issue, the TransMilenio system is looking at alternatives to the free feeder services.

Another option is to utilise a sophisticated fare technology to fare integrate feeder and trunk services without close physical integration. In this case, the feeder stop may be on a side street near the trunk corridor. Using smart card technology, the customer will validate his or her fare card upon both exiting the feeder system and upon entering the trunk system. The physical transfer between the feeder and trunk route may imply walking across a standard intersection with no special segregation for public transport customers. To make this type of transfer

Fig. 11.84 and 11.85
At the Banderas intermediate transfer station in Bogotá, customers cross a weather-protected sky bridge to go from the green feeder vehicles to the red trunk vehicles.
Left photo by Lloyd Wright
Right photo courtesy of ITDP

possible, a fairly sophisticated fare technology system must be in place. The smart card must record not only the location of the transfer but the time between the transfers. The customer will likely be given a time limit to reasonably make the transfer; otherwise, the transfer will be considered two separate trips requiring a separate fare payment. This type of fare-based transfer makes full use of the flexibility afforded by the advent of smart cards but at the same time can introduce complexity into the fare system and can cause some customer confusion.

Alternatively, a simple solution is to charge a separate fare for both the feeder service and the trunk service. One fare would be paid on-board the feeder vehicle and another fare would be paid upon entering the trunk station. The two fares imply that an open transfer could be achieved since no physical enclosure is required between trunk and feeder payment areas. However, the two fares suggest there is less integration between two services; there is no recognition of the overall distance travelled by the customer in the fare calculation. Some customers may be paying disproportionately higher fares due to this imprecision of distance in the fare equation. Further, this approach also implies that customers will have to potentially wait in more queues since fares must be purchased and verified with both services.

11.4.1.2 Closed transfers

Ideally, the feeder vehicles can enter a "closed" space in which a fare-free transfer can take place without concerns over fare evasion. However, this ideal is typically difficult to achieve due to space limitations at intermediate transfer points.

One solution is to simply allow feeder buses to enter the BRT trunk line system briefly and share the BRT station. This approach is being attempted on the Central Norte in Quito. At some wider stations areas along the Central Norte corridor, the combination of trunk and feeder stopping bays functions (Figure 11.86). At other locations, the complementary feeder services originally foreseen in the operational plan have never materialised.

The option of bringing together trunk and feeder vehicles within the same set of stopping bays is rarely used in other systems. Difficulties tend to arise due to space and the different technical specifications between trunk and feeder vehicles. Typically, to make this option work, both the trunk and feeder vehicles must have doorways on the same side of the vehicles in order to share the same platform. This requirement likely means that the trunk vehicles will be forced to have curbside doorways, which creates many other disadvantages as noted in Chapter 7 (*Network and service design*). This configuration will also increase the level of saturation of the station area. If the station is far from saturation this will not cause a major problem, but if it is near to saturation, the combining of trunk and feeder vehicles could lead to a significant deterioration in trunk operating speeds.

Alternatively, a closed environment could be created through the use of segregated pedestrian tunnels or bridges connecting the feeder service to the trunk service. In this case, the feeder stop near the trunk service will be an enclosed environment where only paid customers may be present. The dedicated infrastructure connecting to the trunk station could only be utilised by paid public transport customers. This approach resolves many of the other problems noted in this section, but the infrastructure costs related to the segregated tunnel or bridge may make this option expensive to develop. The cost issue may be particularly acute if there is a considerable distance between the feeder station and the trunk station.

Fig. 11.86
At the Seminario Mayor station of the Quito Central Norte line, customers walk down a ramp from the yellow articulated vehicles to the smaller blue feeder vehicles.
Photo by Lloyd Wright

Fig. 11.87
Bogotá utilises stations with multiple stopping bays in order to permit platform transfers for customers wishing to change from one route to another.
Photo by Lloyd Wright

Fig. 11.88
In some instances, Bogotá also utilises pedestrian tunnels to allow customers move from one corridor to another.
Photo by Lloyd Wright

11.4.2 Interchange stations

As a system expands across a wider network, intersecting stations will require mechanisms to transfer from one trunk corridor to another. An "interchange station" is a facility that permits such transfers, and thus has additional design considerations than a standard station. Interchange stations are relevant to both systems utilising trunk-feeder services as well as systems utilising direct services.

There are several options for facilitating transfers between corridors. These options include:

- Platform transfers (Figure 11.87);
- Underground tunnels / overhead pedestrian bridges (Figure 11.88);
- Interchange facility (multi-bay or multi-storey facility).

A system may use a combination of these interchange options, depending on the local circumstances at the interchange point.

Platform transfers are the most desirable means to permit a customer to change from one route to another. The customer must merely walk a few metres in a protected environment to change services. This type of "closed" transfer is also simpler from a fare verification standpoint as well since no special fare technology is required to discern from those persons "inside" the system and those persons "outside" the system.

However, allowing multiple routes and multiple turning movements within the BRT system can complicate route and intersection design. This complexity is multiplied if there are also various limited-stop and express services. At the crossing of two perpendicular corridors, vehicle turning actions from one corridor to another are required to provide a platform transfer for the customer.

In most cases it is preferable to bring the route to the customer rather than forcing a difficult

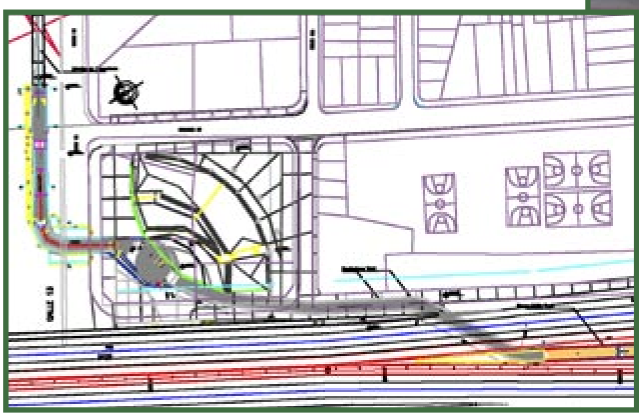


Fig. 11.89 and 11.90
A schematic and external view of the Ricaurte interchange station in Bogotá.
Image and photo courtesy of ITDP

Fig. 11.91 and 11.92
A gradual ramp and enclosed walkway allow customers to comfortably transfer between corridors at Bogotá's Ricaurte station.
Photos courtesy of Carlos F. Pardo

walk across an intersection (and effectively forcing the customer to go to the route). However, there may be instances, where BRT turning movements cannot be realistically accommodated within a complex intersection. The number of required signal phases may create an array of traffic movement problems. Thus, in such instances, it may be necessary to for transfers to take place by customers walking from one corridor to another, typically a diagonal walk across an intersection. To maintain a "closed" environment with paid customers only, a segregated tunnel or pedestrian bridge is required. Further, by providing segregated infrastructure, customers are not subjected to the difficulty of negotiating their way across busy traffic. However, the negative of such a transfer is the usual requirement for a grade change, meaning customers must walk up and down stairs and/or mechanical devices (escalators/elevators) must be provided.

The Ricaurte interchange station in Bogotá provides a quality example of how this type of walking transfer can be accomplished (Figures 11.89 and 11.90).

At the Ricaurte interchange, two perpendicular corridors are connected via a closed pedestrian tunnel. In this case, a gradual slope is used to avoid stairways which would otherwise create difficulties for the physically disabled and elderly (Figures 11.91 and 11.92). This option closely approximates transfer points within a rail underground system. The main advantage of this approach is that it simplifies the intersection design, and that it uses standard station stops in standard locations. The Ricaurte station also includes customer amenities such as restrooms, an information centre, and quality public space.

Another option is to construct an interchange station in which two (or more) trunk lines are physically joined by the same station infrastructure. This infrastructure can take the form of a single-level, multi-bay facility or of a multi-level facility in which one line is physically above the other. This option closely approximates transfer points within a rail underground system. Within this closed environment, passengers then transfer from one route to another. Disadvantages of this approach are the cost of the infrastructure and the space required to construct the facility. However, in comparison to requiring passengers walk from one corridor to another, there is less distance to walk between vehicles.

11.4.3 Terminals

Typically, in BRT systems, terminals are the most important transfer points. They are normally located at the end of each trunk corridor, and provide important transfers between trunk lines and feeder bus lines serving surrounding areas. The design of the interchange facility should minimise both customer and vehicle movements to the extent possible. Thus, the most likely transfer points between complementary routes should be located closely together. As both feeder vehicles and trunk-line vehicles will be staging at the terminal, the movement of vehicles should be devised to avoid congestion. Most typically, feeder vehicles arrive on one side of a platform area with trunk-line vehicles wait on the opposite side (Figure 11.93).

Likewise, the Bogotá system utilises a simple platform configuration to facilitate easy transfers from trunk services to feeder services. Figure 11.94 shows a schematic of the Bogotá terminal platform.

Fig. 11.93
At the El Recreo terminal of the Quito Trolé, customers easily transfer from trunk services to feeder services by crossing a platform.
Photo by Lloyd Wright

Other configurations are also possible. Feeder platforms may be placed in an area somewhat separate from the trunk platforms. This configuration will likely imply that customers must walk farther to access the trunk services. However, such a configuration may be necessary if the number of feeder routes greatly exceed the number of trunk routes (and thus creating a mismatch in terms of platform space). Also, such alternative configurations may also be necessary due to the physical nature and layout of the intended site for the terminal facility. Figure 11.95 is a schematic of a proposed terminal facility in Dar es Salaam in feeder platforms are placed aside the trunk platform area.

Terminals are usually the largest transfer facilities in the system, but the terminals also serve other purposes. Space is typically made available for BRT vehicles to park in order to allow service adjustments. Obvious adjustments are required between operating during busy peak

Fig. 11.95
In this proposed terminal in Dar es Salaam, the feeder platforms are slightly separated from the trunk platform.
Image courtesy of the Dar es Salaam City Council

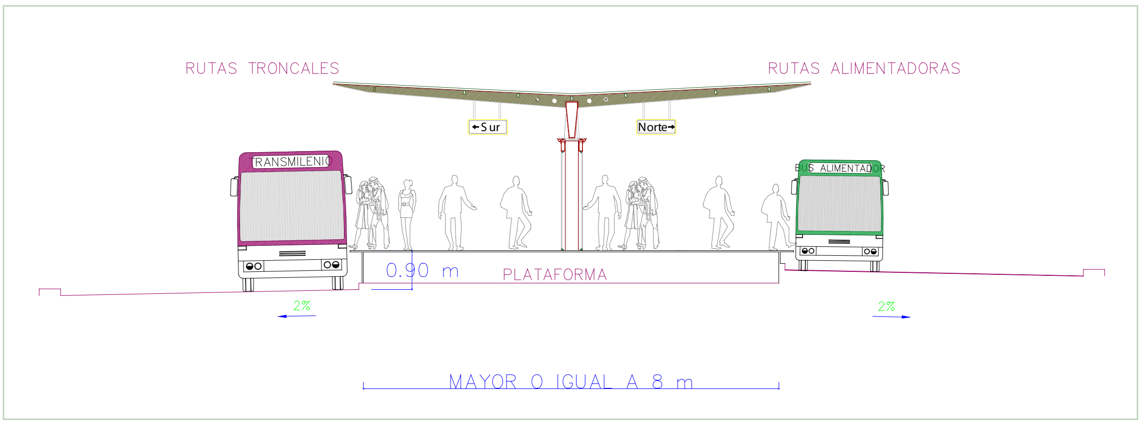


Fig. 11.94
Schematic showing the simple transfer from a trunk vehicle (on the left) to a feeder vehicle (on the right).
Image courtesy of Steer Davies Gleave

periods and non-peak periods. In other cases, the departure times for vehicles are carefully adjusted in order to assure consistent headways.

The overall design of the terminal facility should seek to optimise fluid movements for both vehicles and customers. Appropriate spacing should be created to allow vehicles to comfortably move in and out of position at the stopping bays. Figure 11.96 provides a schematic of an entire terminal facility in Bogotá.

The terminal design must also take into account required turning movements of BRT vehicles. In the case of articulated and bi-articulated vehicles additional space is required for the vehicles to safely and easily complete a 180 degree turn. Figure 11.97 shows the turning space required for an articulated vehicle (18-metre vehicle) to safely turn around.

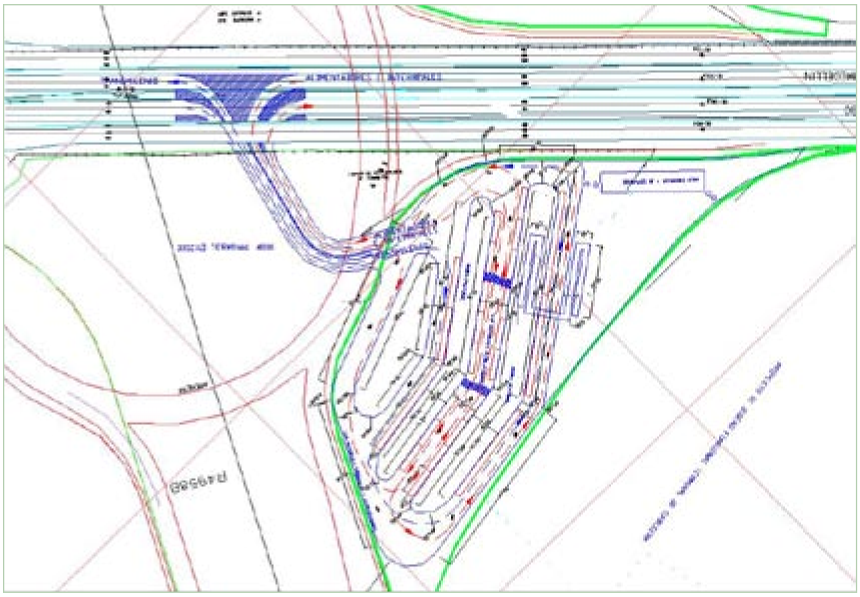


Fig. 11.96
Schematic of all platform and customer facilities at the Calle 80 terminal in Bogotá.
Image courtesy of Steer Davies Gleave

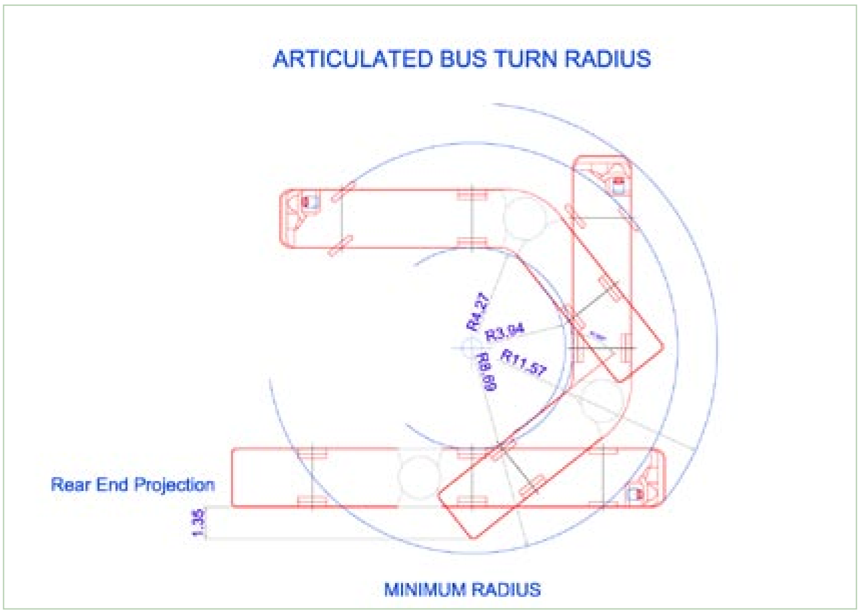


Fig. 11.97
Required turning radius to permit an articulated vehicle to safely change directions.
Image courtesy of ITDP

Whether or not the facility is designed for fare-free transfers will have a significant impact on the facility's design. Fare-free transfers mean that passengers can move from feeder services to trunk-line services without an additional fare. If an additional fare payment is required, then space must be given to fare collection and fare verification activities (Figure 11.98). The physical division between the different fare areas must also be sufficient to avoid problems with fare evasion.

Given the large numbers of passengers passing through terminal areas, design against crimes such as pick-pocketing should also be

Fig. 11.98
To pass from the feeder side of the platform to the trunk side of the platform, customers in Bogotá must pass through fare payment and fare verification infrastructure.
Photo by Lloyd Wright

Fig. 11.99, 11.100, and 11.101

The architectural design of terminal facilities in Quito (top left photo), Bogotá (left photo), and Guayaquil (photo above) serve the functional purposes of efficient customer and vehicle movements as well as serve the aesthetic image of the systems.

Photos by Lloyd Wright

considered. Thus, measures such as security cameras may be appropriate.

Terminals may also serve a range of customer service functions. Some of the provided facilities may include information kiosks, lost and found offices, restrooms, and commercial establishments. Within the Bogotá TransMilenio system, many of the terminals also include "SuperCADE" centres where customers can access a range of municipal services. Allowing shops within transfer facilities is possible but can create an array of complications, including litter and security issues. It is also recognised that some systems intentionally elect not to provide additional services. These system designers feel that the most important task is to keep passengers moving through the system, and that additional services are an impediment to that over-arching goal.

The architectural design of terminals can either mimic the style of the system's stations or take on a different look. Terminal platforms are typically not enclosed with walls since entrance to the terminal site is controlled from a distance (Figure 11.99). Terminal facilities in cities such as Bogotá and Quito have high ceiling designs with modern roof structures (Figure 11.100). Guayaquil has created a great sense of space through its terminal design that features an ornate lattice structure (Figure 11.101). The scale and style of these facilities imparts an impression of importance to the customer and helps to instil the system's professional image.

11.4.4 Depots

Depot areas serve an array of purposes including bus parking areas, re-fuelling facilities, vehicle washing and cleaning, maintenance and repair areas, administrative offices for operators, and employee facilities.

11.4.4.1 Depot location

Depots are generally, but not always, adjacent to terminals. Normally, the BRT vehicle will enter the terminal several times a day, but it will generally enter the depot only if it is being taken out of service, either because it is a non-peak period, because it is the end of the day, or because it is in need of repairs.

Ideally, depots will be located at or adjacent to terminal facilities, so that depot parking can also be used for BRT vehicles coming out of service for off-peak periods without having to travel a long distance to return to a depot (Figure 11.102). Travel between the depot and terminal areas create “dead kilometres” since fuel and other expenses are consumed without generating any passenger revenues. These dead kilometres can considerably increase overall operating costs. Such separation can also create service irregularities, especially if the BRT vehicles are delayed in mixed traffic congestion while travelling from the depot.

However, since depots can consume considerable space, the location is often dependent upon the economical acquisition of sufficient property. In some cases, sufficient land is not available near a terminal site and any site acquisition can be quite costly. Thus, for example in TransJakarta, the depot area is located a considerable distance from the system’s two terminals. BRT vehicles must not only travel a long distance from the depot in the morning and to the depot in the evening, but must travel to depot parking during the non-peak periods. As an alternative to locating the depot nearby the terminal, it is possible to increase the amount of temporary vehicle parking at the terminal area or through intermediate parking facilities. However, again, there is often a limitation on sufficient terminal parking to accommodate all the vehicles.

Terminals and depots for BRT may also be integrated with other transport facilities. In Dar es Salaam, a terminal and depot is being planned in the site of the long-distance bus services (Figure 11.103). This co-location of urban and long-distance services holds benefits both to the customer as well as the private operators. Customers are able to easily transfer from the long-distance services into the BRT system. The private operators may also gain benefit in terms of any shared facilities with long-distance operators.

11.4.4.2 Number of depot facilities and ownership

In many cases, it is desirable to provide enough depots so that each operator controls its own maintenance and parking facilities. Most private operators, if they own the buses, like to have control over their own depot so that they can take responsibility for the security, maintenance, and repair of their buses. The buses represent the biggest corporate asset, and private protection of the long term survival of this asset

Fig. 11.102
In Bogotá, most depots are located next to the terminal areas in order to improve operational efficiency.
Photo courtesy of Oscar Diaz and Por el País que Queremos (PPQ)

Fig. 11.103
The BRT terminal and depot in Dar es Salaam is being integrated with the long-distance bus terminal.
Image courtesy of the Dar es Salaam City Council

is one of the critical benefits of having private operators. The number of depots in a BRT system will therefore be partly a function of the number of private operators.

In the case of TransMilenio, for instance, in Phase I there were three terminals, each one under the control of a different operator. The trunk-line vehicles were stored at these depots. The feeder buses may be stored at smaller depots under the control of the private feeder companies. These facilities are generally in fairly remote locations near the feeder routes where low-cost land is available. However, there may also be circumstances where the feeder-line operators share depot facilities with the trunk-line operators. If some firms operate both feeder and trunk services, then it can be more cost effective for such firms to utilise the same depot area (Figure 11.104). Also, depot services may be a profit centre for some trunk operators who have the depot space and capacity to also provide re-fuelling, repair, and maintenance services to feeder operators.

However, the number of operators should be determined in a manner that maximises system competition while also permitting administrative and management efficiency. For this reason, the number of operators can often exceed the realistic number of depot sites. In the extreme of a system with only one terminal and one depot, then all operators will have to share a single terminal and depot. In these cases, clear contractual language will be required to denote responsibilities at the site.

Regardless of whether there is one or multiple operators at a depot facility, site ownership should be maintained by the public authority. The operators may possess ownership-like responsibilities during the time of their concession, but at the termination of the concession, the public authority will wish to retain a high degree of flexibility. The next firm to gain the operating concession may or may be the same as the existing company.

If a depot location is already owned by a private operator, then it may not be possible for the public authority to assume ownership right away. Expropriation costs may be exorbitantly high and the legal process can be quite difficult. It may be necessary to move through the first concession period with the existing operator in full control of the site.

11.4.4.3 Depot sizing

The size of the terminals and depots depends greatly on the amount of vehicle parking needed, and the number of vehicles likely to need repairs. The configuration of the parking area can be a trade-off between parking efficiency and ease of entry. Some configurations may require some vehicles to be backed out which can be difficult with articulated and bi-articulated vehicles. Further, a densely packed parking area may be relatively space efficient, but it can also lead to occasional damage to vehicles bumping into one another.

Fig. 11.104
At the Usme depot in Bogotá, the green feeder vehicles are maintained at the same facility as the red trunk vehicles.
Photo by Lloyd Wright

Local land prices will likely determine the flexibility available with the depot design. High land prices and a restricted depot area will necessitate some creativity in the layout of the area.

11.4.4.4 Depot layout

The internal design of the depot area should allow for a logical movement of vehicles based on their typical requirements. Figure 11.105 shows a typical layout for a depot area.

Vehicles will enter the depot area as they are instructed by the control centre to temporarily come out of service. As BRT vehicles enter the depot, they are visually inspected at point 1 in Figure 11.105. The vehicle is classified as "green" (operational), "yellow" (in need of minor repairs), or "red" (in need of major repairs).

If the bus is classified as "green", it will typically first move to refuelling. Here fuel levels and vehicle kilometres are checked as a way of monitoring usage and operating costs. In Bogotá, a digital monitoring device records the pertinent vehicle information upon entering the re-fuelling area (Figure 11.106). If required, the vehicle will be re-fuelled at this time (Figure 11.107).

From the re-fuelling area, the vehicle will likely be either washed or placed in a parking bay. The exterior of the vehicle will typically be washed once per day. Most often, the washing occurs after the vehicle's final run of the day. The vehicle's interior may be cleaned upon each entry into the depot area, even if the vehicle is to return for the afternoon peak period. Maintaining a pristine interior area does much to send a positive message to the customer as well as psychologically discourages any littering. In some systems, such as the Quito Ecovía corridor, the vehicle interior is cleaned after each pass through the corridor. The cleaning in this case is actually done at the terminal platform (as opposed to within the depot area).

The washing area should be designed to facilitate easy access to all parts of the vehicle. A channelised groove with drainage permits the washing of the vehicle's underside (Figure 11.108). Special scaffolding equipment permits washing of the vehicle's roof (Figure 11.109). In some depots in Bogotá, water recycling facilities have been established in order to permit re-use of the water from washing (Figure 11.110). Such recycling not only

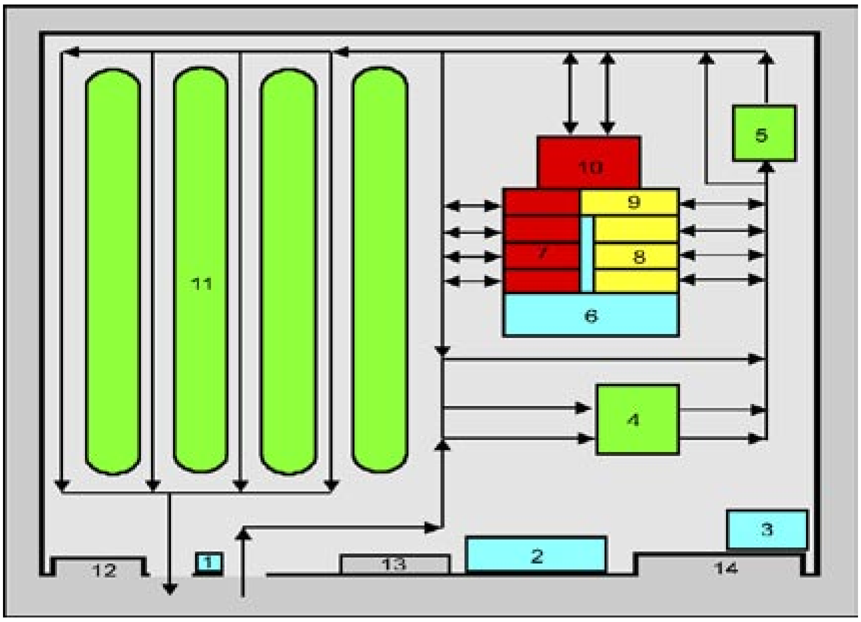


Fig. 11.105
Standard layout for a depot area

1. Gate and visual inspection area;
2, 3, and 6. Administrative offices for the concessioned operators;
4. Refuelling area;
5. Vehicle washing and cleaning area;
7, 10. Major repairs;
8, 9. Minor repairs and maintenance;
11. BRT vehicle parking;
12. Private vehicle parking.

Green: Operational vehicles
Yellow: Vehicles requiring minor or routine maintenance
Red: Vehicles requiring major repairs

Fig. 11.106 and 11.107
Upon entering the re-fuelling area, a digital monitoring device (left photo) records the pertinent vehicle details (e.g., fuel level, odometre). If fuel is required, an attendant will then re-fuel the vehicle (right photo).
Photos by Lloyd Wright

Fig. 11.108, 11.109, and 11.110

A channel allows the underside of the vehicles to be washed (left photo) while scaffolding permits the top of the vehicles to be washed (right photo). A waste water pond helps to facilitate water recycling in Bogotá.

Photos by Lloyd Wright

improves the environmental aspects of the system but can also reduce operating costs.

If the BRT vehicle is classified as "yellow", it is moved to the minor maintenance area (Figure 11.111). From the minor maintenance area a vehicle may return to service the same day or by the next morning. This area may also perform routine checks on the vehicle based on the total kilometres travelled.

If the vehicle is classified as "red", it goes to the major maintenance yard, and is replaced by a stand-by vehicle. A channelled work space below each vehicle permits repair staff to easily access the vehicle chassis for inspection and repair (Figure 11.112). Typically, a certain percentage of vehicles (5 to 10 percent) of the fleet are held in reserve to replace vehicles undergoing maintenance. However, in other systems, a just-in-time (JIT) philosophy prevails where all vehicles are fully utilised.

Sufficient parking space must be provided to hold the vehicle fleet during off-hour periods. The parking area design should also maximise easy entry and departure movements of vehicles. The numbering and assignment of the parking bays can provide efficient control over the fleet (Figure 11.113).

Fig. 11.111

Vehicles are periodically removed from service for routine evaluation and maintenance.

Photo by Lloyd Wright

Fig. 11.112

A channel beneath the work area allows technical staff to service the underside of the vehicle.

Photo by Lloyd Wright

Fig. 11.113
Efficient organisation of the fleet parking improves management control over the depot area.
Photo by Lloyd Wright

Some private vehicle parking may also be required at the depot area. Certainly, access for emergency vehicles should be included in the design. In some cases, not all employees may be able to utilise the BRT system to arrive at work. Since the drivers, mechanics, and other employees will likely need to arrive prior to the start-up of the system in the morning, alternative arrangements should be considered. At the Bogotá Américas depot, bicycle parking is provided for the staff (Figure 11.114). Providing good pedestrian and bicycle access to the depot area helps to encourage staff to utilise sustainable forms of transport (Figure 11.115).

Spare parts storage is typically located near the maintenance and repair areas. The extent to which parts storage is required depends in part on the procurement practices of the particular operating company. Some firms may prefer to purchase in bulk and thus retain a fairly substantial spare parts inventory. In other cases, a just-in-time (JIT) philosophy may prevail and the operating company may hold just a minimum of spare parts (Figure 11.116). The operating company "Sí 99" in Bogotá maintains a very

Fig. 11.114
In Bogotá, system staff are provided with bicycle parking at the depot site.
Photo by Lloyd Wright

Fig. 11.115
A cycle way provides direct access to the nearby Américas depot in Bogotá.
Photo by Lloyd Wright

Fig. 11.116
Store rooms for spare parts should be planned into depot design.
Photo by Lloyd Wright

Fig. 11.117
Makeshift trailers provide office and storage space for suppliers to the TransMilenio operators.
Photo by Lloyd Wright

lean inventory in order to minimise costs. In fact, the spare parts are part of the contractual arrangements with the BRT vehicle supplier who must provide on-site service. Since this type of close manufacturer-operator relationship was not foreseen at the outset of the depot construction, facilities were not provided for the manufacturer offices. Instead, provisional trailers have been set-up to accommodate manufacturer offices and supplies (Figure 11.117).

Offices for operating companies are likely to be best provided at the depot areas. By being located at the depots, operating company officials can better monitor activities and oversee staff (Figure 11.118). The administrative offices may also include conference and training facilities.

Finally, the depot area should also provide facilities catering to the needs of staff such as drivers, mechanics, and administrative workers. These facilities may include showers and lockers, luncheon areas, and recreational areas (Figure 11.119). The workplace environment should be designed to allow drivers and other employees an opportunity to relax after or in-between shifts as well as prepare prior to the start of a shift.

11.4.4.5 Aesthetic design

Although depot areas are not generally accessible to the public, there still may be many reasons to give attention to the aesthetic qualities of the space. First, depots consume large amounts of urban space and thus are typically quite visible to the general population as well as local residents. Thus, the visual aesthetics of the depot will affect the local population's image of

Fig. 11.118
Administrative office facilities for operating companies are provided at TransMilenio depots.
Photo by Lloyd Wright

Fig. 11.119
Cafeteria for drivers and other staff at the TransMilenio Américas terminal.
Photo by Lloyd Wright

Fig. 11.120 and 11.121
The architecture for the maintenance areas in both Bogotá (left photo) and Guayaquil (right photo) is both aesthetically pleasing and highly functional.
Photos by Lloyd Wright

the system. It is always important to be a good neighbour with populations living near the system. Second, a well-designed work environment can have a positive impact on employee satisfaction and work effectiveness. The maintenance depots of systems such as Bogotá and Guayaquil provide a highly-pleasing appearance to both local residents and employees (Figures 11.120 and 11.121)

The design should protect maintenance workers from adverse weather conditions, such as wind, rain, or strong sun. The maintenance area ceiling height should be sufficient to allow employees to comfortably perform maintenance on the topside of the BRT vehicles.

11.4.5 Intermediate parking facilities

Intermediate parking facilities provide parking for BRT vehicles during off-peak periods, so that the vehicles do not have to return all the way to the depot or the terminal to return to service in the afternoon peak. Bogotá's TransMilenio has two intermediate parking locations.

Some systems will have specific turnabouts midway along a corridor, so that operations can be more closely adjusted to passenger volume. On a very long corridor, significant operational costs can sometimes be saved if for example half of the vehicles do not go all the way to the terminal, but instead turn around at some mid-point, so that more service can be provided on the part of the corridor with the highest demand. Sometimes an important depot and interchange facility is not located at the end of a corridor, but at some mid point, in which case the terminal may be an important turnabout location.

11.5 Control centre

"Everyone in a complex system has a slightly different interpretation. The more interpretations we gather, the easier it becomes to gain a sense of the whole."

—Margaret J. Wheatley, writer and management consultant

A centralised control centre will help ensure smooth and efficient BRT operations. Controlling a high-volume BRT system spread across a major developing city is a complex and highly-involved activity. A centralised control and management system brings with it the following benefits:

- Immediate response to changes in customer demand;
- Immediate response to equipment failures and security problems;
- Efficient spacing between vehicles and avoidance of vehicle "bunching";
- Automated system performance evaluation;
- Automated linkages between operations and revenue distribution.

This section reviews the various infrastructure aspects of developing an effective control centre. Chapter 12 (*Technology*) provides an overview of the various technologies that can be utilised to track and control vehicles.

11.5.1 Location of control centre

The control centre does not need to be located in any one special location. The control centre functions remotely from the corridor through its information and communications system. However, locating the control centre near one of the trunk corridors can be desirable since such a location allows a cost-effective, direct linkage to the system through a fibre optic line at the

Fig. 11.122
A distributed control centre at the Perituba Terminal in São Paulo.
Photo by Dario Hidalgo

time of construction. The control centre must be situated in a place that has highly reliable communications connections and electrical power connections. Since the centre may also be receiving information by way of satellite or infra-red communications, the centre should not be located anywhere signals could be potentially blocked.

There could be some benefits to locating control centre staff in management facilities or in terminal facilities (Figure 11.122). These locations would allow greater interactions between control centre staff and management staff or vehicle operators. This sort of interaction could lead to certain synergies in gaining further insights on system operations.

11.5.2 Control room infrastructure

11.5.2.1 Work space

The control room itself will require particular spatial features. The size of the control room will depend upon the number of workstations required. Since a BRT system is likely to be developed in phases, the control room will probably be only partly utilised during the initial years. However, planning for future space requirements at the outset is probably the best strategy (Figure 11.123). Otherwise, a disruptive move to larger facilities will be required later.

Each control centre operator will require space for a computer terminal, voice communications equipment, and additional work space (Figure 11.124). The number of operator workstations required for the total system is a factor of the size of the system and the number of vehicles each operator can safely control. The quality of the controller software package will play a role as well in determining the number of vehicles a control centre staff person can effectively oversee, but an average of 80 to 100 buses can be reasonably managed by each operator under normal conditions. Additionally, since the operators must be able to clearly communicate

Fig. 11.123
The control centre should be designed with sufficient space for future expansion.
Photo by Lloyd Wright

Fig. 11.124
The work station should provide a comfortable environment with easy reach to all telecommunications equipment.
Photo by Lloyd Wright

Fig. 11.125
Providing office space to the police agency at the control centre helps to ensure good co-ordination between the transport system and security services.
Photo by Lloyd Wright

Fig. 11.126
A large-screen display and vehicle tracking board can help staff and supervisors quickly assess the situation.
Photo courtesy of the Los Angeles County Metropolitan Transportation Authority

with drivers, the acoustical arrangement of the workstations should be considered. If noise from one workstation interferes with the communications in another workstation, then the potential for lost or misinterpreted communications will be a problem.

Other municipal staff, such as police representatives, may also require their own workstations and offices in the control centre (Figure 11.125). Supervisory personnel will likely require work space that allows them to easily oversee the entire control centre operation.

Control centre operators can become fatigued by long hours of looking at monitors and tracking vehicles. Holding focussed concentration for long periods of time can be quite mentally exhausting. Typically, operators will have frequent scheduled breaks in order to maintain their alertness. Thus, the control centre should also have a relaxation area or break area that allows operators to refresh themselves.

Fig. 11.127
Multiple small-screen displays of each critical juncture in the system gives the control team a visual understanding of the system's operation.
Photo courtesy of Queensland Transport

11.5.2.2 Equipment requirements

The ergonomics of the workstation furniture should also be an important consideration. Comfortable seating and correctly adjusted placement of monitor screens can help prevent undue stress and discomfort.

In some instances, it is useful to permit visual tracking of vehicles not only by individual monitors but also by way of a large-screen display for the entire centre (Figure 11.126). The large screen can provide control centre supervisors with a macro-perspective on the system. The large screen would also help in circumstances when multiple staff members are resolving a complex issue together. Alternatively, multiple small screens of critical corridor points can help staff rapidly assess potential problems (Figure 11.127).

The entire control centre facility should have not only high-quality primary systems, but reliable back-up systems as well. Spare workstations should be available in case of a technical problem. Further, back-up electricity generators and telecommunications options should also be part of the infrastructure.

Fig. 11.128
In North America, queue-jumping lanes are used to give preferential treatment to buses at intersections.
Photo by Richard Drdul

11.6 Feeder infrastructure

"O public road, I say back I am not afraid to leave you, yet I love you, you express me better than I can express myself."
—Walt Whitman, poet, 1819–1892

Feeder services will likely provide a substantial percentage of a system's ridership since the feeder corridors are the key link into residential areas. Quality infrastructure should not just be given only to trunk lines. Feeder lines should also receive a high level of quality service; otherwise, a large part of the customer base will never engage the system.

This section discusses several components of feeder infrastructure and service, including road infrastructure, stations, and the fare collection and fare verification process for feeder services. A discussion of feeder vehicle types is found in Chapter 12 (*Technology*).

11.6.1 Road infrastructure

Feeder services typically are not provided with dedicated busways but instead utilise mixed-traffic lanes. Since many feeder routes extend into fairly narrow residential streets, exclusive vehicle lanes is not always a practical option. However, there may be instances where road spacing permits exclusive feeder bus passing lanes or feeder "queue jumping" lanes. A queue jumping lane is an exclusive bus lane at a signalled intersection (Figure 11.128). By entering this exclusive lane the vehicle is able to jump ahead of other waiting vehicles. A separate traffic light for the bus lane can in fact give the feeder vehicle a few seconds of a head start against the other traffic.

Passing lanes may also be feasible in sections of the roadway that

Fig. 11.129
Providing standard feeder vehicles with dedicated right-of-way at key junctures can do much to improve average travel speeds.
Photo by Lloyd Wright

have sufficient width. Even a relatively short passing lane can be beneficial if it permits the feeder vehicle to avoid an area prone to congestion. London has successfully utilised short passing lanes with its conventional bus services (Figure 11.129). The London passing lanes have been effective in reducing the unpredictability of bus schedules due to traffic congestion.

Unlike busways, feeder vehicles typically use the lanes adjacent to the street curb rather than in the median. Thus, any bus lanes for feeder services may not be protected by a barrier from the mixed traffic. In many cases, the mixed traffic will need to access the curb lane in order to negotiate turns or to access parking. Under such conditions, infringement of the bus lane by private vehicles can undermine its usefulness. To combat private vehicles from illegally entering the passing lane, London utilises enforcement cameras that will record the license plate number of vehicles using the bus only lane. The key to maintaining the usefulness of a bus lane resides in the enforcements mechanisms utilised.

Since feeder vehicles are typically smaller than trunk-line vehicles, the need for special surface materials (such as concrete) is not necessary. The lower vehicle weights do not damage streets to the same degree. Nevertheless, the proper maintenance of asphalt streets is important in maintaining the quality of the feeder fleet and in reducing maintenance costs. Thus, feeder streets should receive priority treatment for repairs and maintenance. Also, feeder vehicles will likely have less suspension support than trunk-line vehicles, so the smoothness of the ride and the comfort of the customers will be more dependent upon road conditions.

11.6.2 Feeder stations / shelters

Feeder services should not merely replicate the previous informal services that preceded the introduction of the BRT system. While previous services likely boarded and alighted passengers at random locations, depending on customer preferences, a formal feeder service should establish formal station areas. Just as travel times along the trunk lines benefit from well-spaced station, the same holds true for feeder corridors. However, it may be justifiable to place feeder stations somewhat closer together than the range recommended for trunk-line services, which is approximately 300 metres to 1,000 metres. Since pedestrian conditions along feeder routes may be less developed than trunk-line routes, it can be difficult for some residents to access the system in such circumstances. The actual distance spacing between feeder stations will depend upon several factors, including the population density of the area as well as the location of major trip destinations and origins.

Feeder stations or shelters will likely not be as architecturally sophisticated as trunk-line stations, but nevertheless, the feeder stations should provide a quality wait environment. A shelter should be provided to protect customers from rain and heat. Given cost considerations and the nature of feeder services, the shelter does

Fig. 11.130
While feeder shelters will be more modest in scope than trunk stations, some basic customer comforts, such as rain protection and seating should be considered.
Photo by Lloyd Wright

Fig. 11.131
Vegetation is cleverly used as a bus shelter in Bangkok.
Photo by Lloyd Wright

not need to be closed as is the case for the trunk line. However, a roof cover along with back and side panels can be appropriate (Figure 11.130). Use of natural vegetation can also make for an intriguing structure (Figure 11.131).

In many instances, feeder shelter construction and maintenance can be funded in part by panel advertising. However, in such instances, the advertising should not detract from the functionality of the shelter. For example, advertising panels should not block the vision of passengers towards the arriving feeder vehicle. Panels should also include a full system map. Further, third party construction of a shelter should follow strict design guidelines developed by the public agency.

Since wait times for feeder services tend to be somewhat longer than trunk-line services, some shelter amenities may be appropriate. For example, seating or a leaning post can be a low-cost way of significantly improving the comfort of those waiting.

11.7 Infrastructure costing

"You and I come by road or rail, but economists travel on infrastructure."

—Margaret Thatcher, former UK Primer Minister, 1925–

Capital costs consist of both infrastructure costs and any related land or property acquisition costs. An initial analysis of these costs can help focus the possible design work on financially realistic options. Based on the preferred design characteristics in conjunction with the size of the initial phase of the project, a city can determine if the capital cost estimates are in line with realistic financial resources. Cities should be encouraged to experiment with a range of possibilities with respect to both design options and the amount of financial resources likely to be available. If the design team is overly pessimistic about the likely financial resources available, then the quality of the system may be needlessly compromised by an inadequate design. Several iterations of physical designs and operational designs are likely before finding a balance between system cost and system performance.

11.7.1 Range of infrastructure costs

Infrastructure costs for BRT systems can vary considerably depending on the complexity and sophistication of the system as well as the local economic and topographical characteristics. Successful systems have been developed for as little as US$500,000 per kilometre (Taipei).

Bogotá's TransMilenio by many measures is a state of the art system, and this sophistication is reflected in its relatively high-cost infrastructure. Phase I of Bogotá's TransMilenio cost US$5.4 million per kilometre. The three corridors in Phase II cost from US$9 million per kilometre to US$15.9 million per kilometre. The higher costs in Phase II were due to the need to build some new bridges, a new highway interchange with the BRT system, and tunnels. Also, Phase II required a significantly higher amount of land acquisition. These items can dramatically escalate the total costs.

One of the major considerations is the volume of passengers the busway has to accommodate. Bogotá's TransMilenio required a capacity of over 45,000 passengers per direction at the peak hour, which required two full lanes in each direction, and multiple station platforms at each stop, which increased the construction cost. Another major consideration is whether or not to reconstruct the entire roadway. BRT systems do impose heavy wear and tear on roads, and because repairs often require shutting down the system for a time, it is advisable to use materials able to withstand a maximum axle load with minimal repairs. Concrete is sometimes used for the entire roadbed. At a minimum, the roadway along the stations should be in concrete.

In some cases, BRT systems are developed when a major road is due for a scheduled rehabilitation. In this way, the major of the cost could be covered from the ongoing capital budget. Another factor is the quality of footpaths, bike paths, public space, street furniture and other amenities in the corridor. Bogotá dramatically improved the TransMilenio corridors, not only for the BRT vehicles but also for cyclists, pedestrians, and persons enjoying public space. All of these costs are folded into the overall cost per kilometre. These measures make a big difference in terms of the attractiveness of the system.

However, in general, developing-city BRT systems will cost in the range of US$1 million to US$7 million per kilometre. Some of the principal factors in determining the actual infrastructure costs will include:

- Number of exclusive lanes;
- Materials utilised in the construction of the lanes (asphalt or concrete);
- Expected system capacity, and thus the capacity and size of stations, terminals, and depots;
- Local construction costs;
- Amount of property expropriation required.

Table 11.4 lists the actual infrastructure costs for Phase I of TransMilenio.

11.7.2 Estimation techniques

The limited number of BRT systems to date combined with the lack of a shared costing database makes local estimations of infrastructure costs somewhat difficult. However, there are a few options for developing an initial estimate of infrastructure costs. These options include developing estimates based on:

- Costs from BRT systems in other cities with adjustments based on local design and macroeconomic factors;
- Similar past projects in similar areas of the municipality; such projects could include road expansion efforts and previous bus improvement measures;
- Informal discussions with local contractors and engineering trade associations; and,
- Survey work by consultants, which may incorporate all of the above estimation techniques.

More accurate cost estimates will be generated at a later time when the project approaches the implementation stage. In the early development phase, the estimation techniques presented above should help narrow the design and performance characteristics into a relatively focused area of values.

Based on cost data from existing developing-nation BRT systems and inputs from BRT experts, a BRT cost calculator has been developed to

Table 11.4: BRT construction cost breakdown, Bogotá's TransMilenio

Component	Total Cost (US$)	Cost per Kilometre (US$)
Trunk line busways	94.7	2.5
Stations	29.2	0.8
Terminals	14.9	0.4
Pedestrian overpasses	16.1	0.4
Depots	15.2	0.4
Control centre	4.3	0.1
Other	25.7	0.7
Total	198.8	5.3

Table 11.5: Runway costs (Phase I project of 50 kilometres)

Item	Cost (US$) per unit	Units	Reference info	Quantity requested	Cost (US$)
Busway construction / roadway reconfiguration			No. of km	Enter no. of km of each type	
Use existing asphalt on busway / new concrete at stations	150'000	US$ per kilometre	50		0
New asphalt on single lane busway / concrete at stations	700'000	US$ per kilometre	50	50	35'000'000
New concrete on single lane busway / concrete at stations	1'250'000	US$ per kilometre	50		0
New asphalt on double lane busway / concrete at stations	1'400'000	US$ per kilometre	50		0
New concrete on double lane busway / concrete at stations	2'500'000	US$ per kilometre	50		0
Lane separators			No. of km	Enter no. of km of each type	
Basic separator cones	1'000	US$ per kilometre	50		0
7 cm separator blocks	5'000	US$ per kilometre	50	50	250'000
50 cm separator wall	25'000	US$ per kilometre	50		0
Busway colouration			No. of km	Enter no. of km of each type	
No colourisation	0				0
Colourised at intersections only	5'000	US$ per kilometre	50		0
Busway with fully colourised lanes	50'000	US$ per kilometre	50	50	2'500'000
Landscaping			No. of km	Enter no. of km of each type	
None	0	US$ per kilometre	50		0
Basic (1 tree per 50 metres + plantings)	10'000	US$ per kilometre	50		0
High-quality (1 tree per 10 metres + sculptures)	50'000	US$ per kilometre	50	50	2'500'000
Intersection underpass				Enter no. of underpasses	
No underpasses	0	US$ per underpass			0
Busway underpass	3'500'000	US$ per underpass		2	7'000'000
Passing lanes at stations (i.e. express services)			No. of stations	Enter no. of stations w/ passing	
No express services	0	US$ per station	100	0	0
Express services	50'000	US$ per station	100		0
				Runway sub-total	47'250'000

Table 11.6: Station costs (Phase I project of 50 kilometres)

Item	Cost (US$) per unit	Units	Reference info.	Quantity requested	Cost (US$)
Station construction			No. of stations	Enter no. of stations of each type	
3 metre wide stations	200'000	US$ per station	100	100	20'000'000
5 metre wide stations	350'000	US$ per station	100		0
Station air conditioning / heating			No. of stations	Enter no. of stations with each type	
No air conditioning	0	US$ per station	100		0
Full air conditioning / heating	100'000	US$ per station	100		0
Air conditioned / heated shelter inside station	30'000	US$ per station	100		
Mist generators / fans	5'000	US$ per station	100	100	500'000
Automatic sliding doors at boarding interface			No. of stations	Enter no. of stations w/ each type	
No sliding doors	0	US$ per station	100		0
Sliding doors (8 doors per station)	40'000	US$ per station	100	100	4'000'000
Sliding doors (16 doors per station)	80'000	US$ per station	100		
Station identification - sign post			No. of stations	Enter no. of stations with post	
No station identification post	0	US$ per station	100		0
Station identification post	800	US$ per station	100	100	80'000
Maps and information			No. of stations	Enter no. of stations or kiosks	
No maps or information	0	US$ per station	100		0
Maps at stations	3'000	US$ per station	100		0
Maps at stations and in vehicles	6'000	US$ per station	100	100	600'000
Information kiosks	30'000	US$ per kiosk		5	150'000
Recycling receptacles at stations			No. of stations	Enter no. of stations w/ each type	
None	0	US$ per station	100		0
Receptacles at station	1'000	US$ per station	100	100	100'000
Station security			No. of stations	Enter no. of stations w/ each type	
No security measures	0	US$ per station	100		0
Emergency callbox	1'500	US$ per station	100		0
Security cameras	8'000	US$ per station	100	100	800'000
				Station sub-total	**26'230'000**

Table 11.7: Fare and ITS costs (Phase I project of 50 kilometres)

Item	Cost (US$) per unit	Units	Reference info.	Quantity requested	Cost (US$)
Fare collection readers			No. of stations	Enter no. of stations w/ each type	
Smart card system (4 readers per station)	10'000	US$ per station	100	100	1'000'000
Magnetic strip system (4 readers per station)	7'000	US$ per station	100		0
Coin-based system (2 readers per station)	1'500	US$ per station	100		0
Fare collection turnstiles			No. of stations	Enter no. of stations with turnstiles	
Rotating turnstile (4 turnstiles per station)	7'000	US$ per turnstile	100		0
Gate-arm turnstile (4 turnstiles per station)	2'800	US$ per turnstile	100	100	280'000
Fare registering unit / vending machine			No. of stations	Enter no. of stations with machines	
Smart card system	15'000	US$ per machine	100	100	1'500'000
Magnetic strip system	10'000	US$ per machine	100		0
Coin-based system	0	US$ per machine	100		0
Fare media			No. of cards	Enter no. of cards	
Smart card system with microprocessing ability	3.50	US$ per card		500'000	1'750'000
Smart cards w/o microprocessing ability	1.20	US$ per card			0
Magnetic strip cards	0.05	US$ per card			0
Coin-based system	0.00	US$ per card			0
Fare system software			No. of software	Enter no. of software	
Smart card system	500'000	US$ per software	1	1	500'000
Magnetic strip system	300'000	US$ per software	1		0
Coin-based system	100'000	US$ per software	1		0
Intelligent Transportation Systems (ITS)			No. of stations/inters.	Enter no. of stations/inters.	
No ITS options	0	US$ per station	100		0
Green light phase extension for BRT	20'000	US$ per intersection	100	20	400'000
Real-time information displays	7'500	US$ per station	100	100	750'000
Broad-band service at stations/terminals	750	US$ per station	100	100	75'000
Fare system and ITS sub-total					**6'255'000**

Table 11.8: Integration infrastructure costs (Phase I system of 50 kilometres)

Item	Cost (US$) per unit	Units	Reference info	Quantity requested	Cost (US$)
Pedestrian crossings			**No. of stations**	**Enter no. of stations with crossings**	
No pedestrian crossing improvements	0	US$ per station	100		0
Pedestrian crosswalk with signal	20'000	US$ per station	100	75	1'500'000
Pedestrian bridge	300'000	US$ per station	100	25	7'500'000
Pedestrian access to station areas			**No. of busway km**	**Enter km of improved footpaths**	
No improvements	0	US$ per km	50		0
Improvements to pedestrian access ways	35'000	US$ per km	50	100	3'500'000
Bicycle integration			**No. of stations**	**Enter no. of stations w/ parking**	
No bicycle integration	0	US$ per station	100		0
Bicycle parking at stations	8'000	US$ per station	100	50	400'000
Taxi integration			**No. of stations**	**Enter no. of taxi stands**	
No taxi integration	0	US$ per station	100		0
Formal taxi stands at stations	60'000	US$ per station	100	20	1'200'000
Park-and-ride facilities				**Enter no. of facilities**	
No park-and-ride facilities	0	US$ per facility			0
Kiss-and-ride facilities only	40'000	US$ per facility		2	80'000
Park-and-ride facility (open lot parking)	1'500'000	US$ per facility		2	3'000'000
Park-and-ride facility (multi-level parking)	10'000'000	US$ per facility			0
				Integration infrastructure sub-total	**17'180'000**

give cities an initial estimation of infrastructure costs. Actual costing will depend much on local conditions and circumstances. However, the BRT cost calculator is useful in alerting project developers to the costing items that should be considered in planning a system. The actual cost calculator can be accessed at the following web site: www.itdp.org/programs/BRT.

An example use of the cost calculator is provided below. In this case, costing is estimated for a hypothetical Phase I project of 50 kilometres of trunk busways.

Table 11.5 summarises the runway construction costs for this hypothetical project. In this case, asphalt busways with concrete at the station areas have been selected. Budget is also provided to colourise the entire trunk busway.

Table 11.6 summarises the station costs for the hypothetical system. In this case, the stations are assumed to be 3 metres in width with sliding doors, customer service maps, and security cameras. There is also assumed to be a station at every 500 metres of trunk busway.

Table 11.7 summarises the technology costs associated with the system. These cost items include the fare collection and fare verification equipment as well as any applications of Intelligent Transportation Systems (ITS). In the case of this example, smart card technology will be utilised as well as some priority signalisation at intersections, real-time information displays at stations, and broad-band internet services at stations.

Table 11.8 summarises the cost of integration infrastructure associated with this hypothetical system. In this instance, it is assumed there will be either a new pedestrian crossing or a grade-separated pedestrian bridge at each station. Also, it is assumed that this system will include 100 kilometres of upgraded footpaths in the areas near the stations. Additionally, this system includes bicycle parking at stations, metred taxi integration facilities, and some park-and-ride facilities.

Table 11.9 summarises the remaining infrastructure cost items, which include feeder infrastructure, terminals, depots, intermediate transfer stations, and any land acquisition requirements. For this hypothetical system, it is assumed there will be 75 kilometres of feeder services, one control centre, two terminals and two depots, four intermediate transfer stations, and substantial land acquisition for the terminals, depots, and park-and-ride facilities.

In addition to the line items outlined in tables 11.6 through 11.9, the project team should also include contingency costs within any preliminary budget. The contingency item helps to predict any unforeseen infrastructure costs. Ideally, the preliminary budget will be appropriately conservative in nature so that decision-makers will not be faced with expenditure over-runs at a later date.

Table 11.10 summarises the sub-totals from each of the preceding costing categories. The total

Table 11.9: Other infrastructure cost items (Phase I project of 50 kilometres)

Item	Cost (US$) per unit	Units	Reference info	Quantity requested	Cost (US$)
Feeder system			**Km of feeder roads**	**Enter no. of km of each type**	
No feeder improvements	0	US$ per kilometre			0
Feeder busway/station improvements	75'000	US$ per kilometre		75	5'625'000
Control centre (including software)			**No. of control centres**	**Enter "1" with the selected type**	
No control centre	0	US$	0		0
Control centre physical construction	1'500'000	US$	1	1	1'500'000
Radio-based control only (equipment)	100'000	US$	1		0
GPS system (equipment)	1'000'000	US$	1	1	1'000'000
Software	3'000'000	US$	1	1	3'000'000
Terminals and depots				**Enter no. of terminals or depots**	
Terminal facilities	3'000'000	US$ per terminal		2	12'000'000
Depot facilities	5'000'000	US$ per depot		2	20'000'000
Restrooms at terminals	15'000	US$ per terminal		2	60'000
Intermediate transfer stations				**Enter no. of corridors**	
No intermediate transfer stations	0	US$ per corridor			0
Standard intermediate transfer station	400'000	US$ per corridor		4	3'200'000
Large intermediate transfer station for multiple feeder services	1'500'000	US$ per corridor			0
Property acquisition				**Enter no. of sites or km**	
No property acquistion required	0	US$ per site			0
Terminal site in peripheral area1	3'000'000	US$ per site		2	6'000'000
Depot site in peripheral area2	5'000'000	US$ per site		2	10'000'000
Park-and-ride site in peripheral area3	2'000'000	US$ per site		2	4'000'000
Terminal site in central area1	60'000'000	US$ per site			0
Street widening in central district (2 lanes eqv.)	40'000'000	US$ per kilometre			0
				Other infrastructure sub-total	**66'385'000**

1. Assumes 30,000 square metres required for terminal site
2. Assumes 50,000 square metres required for depot area
3. Assumes 20,000 square metres required for park-and-ride site

infrastructure budget projected for this hypothetical project comes to approximately US$180 million, which equates to approximately US$3.6 million per kilometre of trunk services.

Table 11.10: Summary of system infrastructure costs (Phase I project of 50 kilometres)

Cost category	Total projected budget (US$ million)	Cost per kilometre (US$ million / km)
Runways	47.250	0.945
Stations	26.230	0.525
Fare system and ITS	6.255	0.125
Integration infrastructure	17.180	0.344
Other (terminals, depots, land costs, etc.)	66.385	1.328
Subtotal	**163.300**	**3.266**
Contingency (10%)	16.330	0.327
Total	**179.630**	**3.593**

11.7.3 Capital cost and operating cost options

In most BRT systems, the classification of capital costs versus operating costs is important from the standpoint of public versus private investment. The public sector generally provides the capital investment just as it typically funds roadways for private automobiles. Many BRT systems utilise private operators to cover operating costs, and thus such operators obtain access to revenues from fare collection. Some costs, such as vehicles and fare collection equipment, do not automatically fall into either category, and thus the assignment of these costs can depend upon local circumstances.

There are instances when some elements of the BRT system may be strategically moved between capital and operational cost categories. Typically, this situation arises when fare affordability in lower-income countries becomes a significant issue. For example, some African nations have per capita incomes of US$200 or less. Since the cost of vehicles and fare collection equipment will likely not be appreciably different between a low-income and middle-income nation, the costs of such equipment can put significant pressure on total operating costs in low-income nations. Thus, moving some of these costs to the capital cost category can help permit reasonable fare levels without the need for operating subsidies.

Further, it is quite desirable to avoid operating subsidies since the subsidy process adds much administrative complexity to the system, as well as creates opportunities for the misappropriation of funds. A one-off subsidy for capital expenditures is typically a much more elegant manner for applying public funding support.

Moving equipment purchases to the capital cost category can bring with it some unintended consequences. In general, it is best to have the companies utilising the equipment to pay for it and to maintain it. Companies operating buses that they do not purchase or do not own the vehicles will tend to not maintain the vehicles properly. These companies may also not pursue the most cost-effective models at the time of purchase. Thus, public procurement of equipment can result in many misplaced incentives. A compromise to such circumstances is for the public sector to share costs with the private sector. For example, the public sector may provide 50 percent of the vehicle cost while the private firm must pay off the other 50 percent through fare revenues. In this way, the private firm still has an incentive to properly maintain for the vehicle, but the reduced cost means that pressure on cost recovery is lessened.

In general, it is always best for the private sector to purchase their own vehicles, based upon the well-defined specifications developed by the public sector. However, in some instances with low-income nations, it may be necessary to transfer some of the vehicle purchase costs to the capital cost category in order to achieve an affordable customer tariff. It is quite feasible to transfer the burden of the initial investment from private to public hands and to maintain the efficiency of the private sector is achievable. As an alternative to direct public investment in equipment such as vehicles and fare equipment, the public sector could also provide special condition loans or tax incentives that will reduce the impact of the investment on the cash flow and will not get involved the public sector in the actual purchasing process. The key element is to select financial options that will allow the city to achieve affordable fares, maximising the respective resources and capabilities of both the public and private actors.

Fig. 11.132
Some cost items, such as vehicles and fare equipment, could be listed as either capital or operating costs. Shifting all or part of these expenses to one category or another will impact the affordability of fares and the amount of infrastructure investment required.
Photo by Lloyd Wright

There are also circumstances that may permit the shifting of costs in the other direction, from capital costs towards operating costs (Figure 11.132). Some systems have room for higher fare levels and may prefer to reduce their capital borrowing for the initial system infrastructure. In such instances, putting some elements of equipment into the operating cost category can make sense. For example, Bogotá required the private firm with the fare collection concession to include the electronic turnstiles and smart cards as part of the operational bid. The private fare collection firm thus amortises the cost of this infrastructure through their share of the fare revenue. In effect, the concessioned firm is acting as a financing agent for the particular piece of infrastructure.

11.7.4 Land and property acquisition

One of the most variable cost items when comparing different BRT systems is the level of land and property acquisition required. In many instances, the municipality will need to impose eminent domain upon private properties, which is a legal action to take ownership of land and/or property even when the owner is unwilling to sell.

Since the exclusive busways are most typically in the centre median, the private properties along the corridor remain relatively untouched. However, cities wishing to maintain the existing number of mixed traffic lanes may purchase land and properties along the sides of the roadway. Space for terminals and depots can be problematic due to the larger land requirement. However, these sites are often located farther from the centre, and thus more open space and lower cost land are generally available at such peripheral locations.

In instances that property purchases are necessary, infrastructure costs can quickly skyrocket. Infrastructure costs on Bogotá's TransMilenio system jumped from approximately US$5.3 million per kilometre in Phase I to as high as US$15.9 million per kilometre in Phase II. Much of this increase was due to the much greater need for land purchases in the second phase. In Phase I of TransMilenio, approximately 600 plots were purchased. In Phase II, the municipality purchased approximately 4,000 plots (Figure 11.133).

The use of eminent domain law is a highly sensitive political and social issue. Emotions can run quite deep when businesses and families must give up workplaces and homes, especially when such sites have been owned for generations. Further, since low-income groups often live closest to the busiest corridors, social justice issues will also come into play. International lending agencies, such as the World Bank, are quite sensitive to the appropriateness of eminent domain procedures. Failure to handle the property purchases in a fair manner can result in the loss of international financing. For all these reasons, property expropriation must be handled carefully and with the highest degree of transparency.

Some characteristics of a well-designed property purchase programme include:

- Clarity in the procedures;
- Transparency and openness of the process;
- Timeliness in processing and timeliness in resolving conflicts;
- An over-riding sense of fairness in the process.

The World Bank has developed a set of recommended procedures for compulsory purchase programmes in infrastructure projects. Likewise, Bogotá has developed a similar process to fairly deal with property purchases required by the expanding TransMilenio system. The following steps outline the Bogotá process:

1. Map the area plots in relation to the planned BRT system. Design adjustments should be undertaken to minimise land acquisition,

Fig. 11.133
Land and property expropriation in Phase II of TransMilenio greatly increased the overall capital investment.
Photo by Carlos F. Pardo

even if this implies reducing the number of mixed traffic lanes.

2. Determine the property ownership history of any required properties. This process includes investigating land titles, mortgages, and current occupants.
3. Survey the actual activities and socio-economic conditions of existing occupants, in order to define a baseline for potential financial compensation.
4. Assess the property value through independent appraisers to compensate the commercial value of the plots. If only the property tax registrar is used, properties may be significantly undervalued, which may prompt litigation and delays in the purchase process.
5. Estimate the required compensation based on the current property conditions. Also include a value for potential impacts on sales during the relocation process.
6. Offer assistance in searching for relocation options. Provide information on potential alternatives. This assistance should be particularly directed towards any low-income families and other vulnerable groups that are being displaced.
7. Provide a complete and well-documented compensation offer for the displaced inhabitants. It is recommended to include a down payment at this stage to help move the transaction towards completion.
8. If the offer is accepted, provide a fast-track process to complete the transaction documents and issue the down payment. Failure to promptly deliver promised documentation and payments will undermine public confidence in the process and lead to less cooperation in future acquisitions.
9. If the offer is declined due to the amount of the proposed compensation, then both parties can agree to an arbitration process to determine the correct value. This arbitration process should be well-defined at the outset of the purchase programme, and thus be set-up to provide a timely answer.
10. If the offer is declined and the parties do not agree to arbitration, then eminent domain law will be applied. A subsequent legal proceeding will take place in which the property owner(s) can present the case against expropriation or argue for a different compensation value. Given the lengthy duration of potential legal proceedings, the city may request that the court award the handover of the property immediately for system development. The awarded value of the compensation will then be determined at the termination of the legal process.

The key to any land expropriation process is the quality of the property appraisal and the clarity of the procedures to be undertaken. The entire process should be designed to account for all eventualities and to provide timely actions at each step. Even small delays due to legal proceedings can increase construction costs dramatically.

12. Technology

"Any sufficiently advanced technology is indistinguishable from magic."

—Arthur C. Clarke, author and inventor, 1917–

Technological advances with vehicles, fare systems, and communications systems have played a key role in advancing the state-of-art of public transport. Intelligent Transportation Systems (ITS), such as automatic vehicle location (AVL) and real-time information displays, have done much to dramatically improve operational efficiency and customer service. Technology also conjures up images of modernity and sophistication which helps to sell project concepts to both political officials and the public.

At the same time, technology should not supplant the operational design. Instead, technological choices should simply follow from the customer requirements that have been prescribed by the demand analysis and desired operational characteristics. Designing a system around a particular vehicle is bound to lead to compromise. The system should obviously be shaped around the customer and not a piece of technology. For this reason, the technological choices regarding vehicles, fare systems, and ITS are really the last activity in the BRT design process. Once the Operational Plan and much of the Business Plan are completed, then the relevant parameters for the technological options can be defined.

This Chapter outlines the various technological options for vehicles, fares systems, and ITS. As with other aspects of system planning, there is no one right or wrong answer to technology selection. Instead, each option carries with it different sets of benefits that must be weighed against the priorities set by the project developers. As always, the local context is the basis for determining the most appropriate solution for any given situation.

The topics discussed in this chapter are:

12.1 Vehicle technology

"Don't worry, sweetie, don't worry! Nobody in New York notices a bus until it's about to hit them!" (Samantha in "Sex and the City")

—Kim Cattrall, actress, 1956–

Few decisions in the development of a BRT system invoke more debate than the choice of bus propulsion technology and bus manufacturer. However, it should always be remembered that BRT is far more than just a bus. The choice of bus technology is important, as it will strongly influence the system's performance, but vehicle selection is not necessarily more so than the myriad of other system choices.

Regardless of whether the vehicle procurement is public or private, the technical specifications of the vehicle selected will largely have to be set by the system's designers so that they interface properly with the infrastructure.

The current common practice is for the public agency to set vehicle standards while the private sector actually purchases and operates the vehicles. Thus, while a standard set of basic requirements must be met, many decisions, such as vehicle manufacturer, are actually left to the bus operating companies. The public agency will likely develop a detailed set of vehicle specifications that each operator will be required to fulfil. However, it is up to the bus operator, who is paying for the buses, to determine how to best meet the specifications. Thus, within Bogotá's TransMilenio system, different operating companies have selected different vehicle manufacturers. However, thanks to the detailed specifications, from the perspective of the customer, all of the vehicles look and operate identically. This commonality is important to creating and preserving a clear system identity.

Fig. 12.1
The sophistication and attractiveness of a technology are factors to consider, but so are basic issues such as maintenance and operational cost efficiency.
Photo courtesy of Advanced Public Transport Systems (APTS)

Operators purchasing BRT vehicles must weigh many factors in choosing a fuel and propulsion system technology. Beyond basic vehicle prices, there are a host of issues that must be considered. Will the vehicle technology meet required emission standards? Will the size and design of the vehicle fulfil capacity requirements? Does the technology have a history of operating consistently in developing city conditions? Does the technology require maintenance personnel with highly-specialised skills? Are spare parts for the technology expensive and difficult to obtain in a developing city? Are special re-fuelling stations required for the technology? Is the technology selected financially viable? An attractive, sophisticated vehicle technology may entice decision-makers to make an instinctive choice, but nevertheless basic questions about maintenance, spare parts, and operational costs should be an integral part of the decision-making process (Figure 12.1).

12.1.1 Decision-making matrix

Vehicle fleet technology selection, provision, and operation is complex and depends on legal, operational, institutional, and strategic factors particular to each individual case. Figure 12.2 displays a recommended methodology for vehicle selection and provision mechanisms.

Following through the four main activities described in Figure 12.2 can guarantee that the characteristics of the chosen vehicle will meet all the operational requirements necessary to ensure the system's financial viability.

The first and most important activity involves identifying the project's specific needs and requirements for its fleet. Most of this analysis

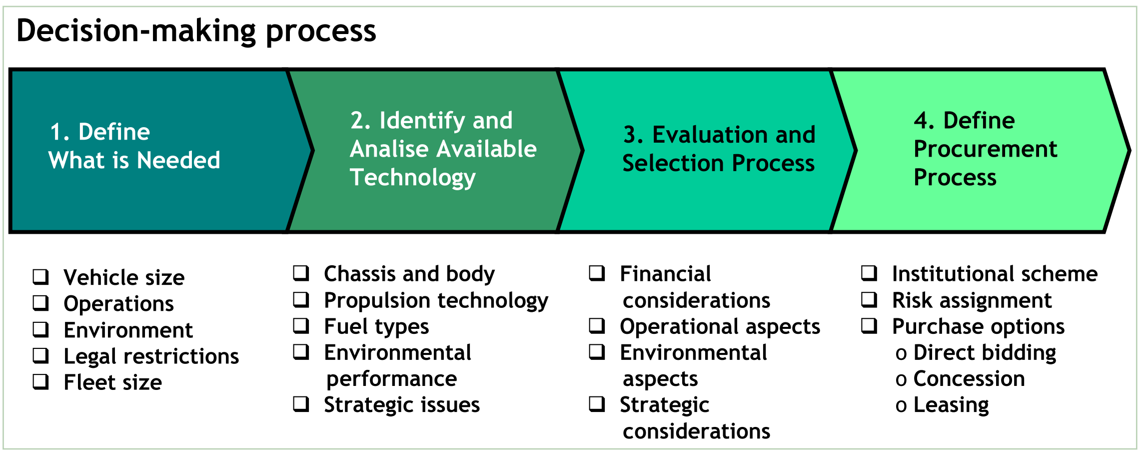


Fig. 12.2
Decision making process for vehicle selection.

Table 12.1: Decision factors for choosing a vehicle technology

Category	Factor
Cost	Purchase cost Maintenance costs Re-sale value in local market
Vehicle features	Passenger capacity Interior design options Aesthetics
Manufacturer support	Manufacturer support office in country Capabilities of manufacturing technical assistance staff Warranty coverage and conditions
Robustness	Track record of technology in a developing city Degree to which specialised skills are required for maintenance and operation Feasibility of making repairs on the road Expected percentage of up-time in operation Reliability Vehicle longevity
Re-fuelling	Re-fuelling time Type and cost of required re-fuelling station
Safety	Strength of body structure Chassis design Brake system effectiveness Anti-fire protection Emergency devices
Environment	Local emissions (NO_X, SO_X, CO, PM, toxics) Global emissions (CO_2, N_2O_4, CH_4) Noise levels Other waste products (*e.g.,* solid waste, waste oil, etc.)
Compliance with local regulations	Maximum weight per axle Height, width, and length restrictions

should already have been done in the operational design process. Vehicle characteristics should not be defined based only on aesthetic or political interests but must be defined based on optimising the system's operations.

It would be a serious mistake to select the vehicle prior to performing the operational analysis. Selecting the vehicle type prior to defining the system's operational design can result in either purchasing far more expensive vehicles than is necessary or vehicles too small to provide the required capacity without serious overcrowding or busway congestion.

Table 12.1 summarises many of the factors that an operator will consider in deciding upon a technology and a manufacturer.

Once the principal system requirements and needs have been identified, there remain many additional technical considerations that need to be decided before finalising the technical specification. In general, the basic decision areas for the vehicle include:

1. Vehicle size;
2. Chassis and body configuration;
3. Interior design options;
4. Fuel and propulsion technology;
5. Aesthetic options;
6. Vehicle docking options.

12.1.2 Vehicle size

The size and required passenger capacity of the vehicle are largely determined by the modelling analysis conducted at the outset of the project. The analysis process will have determined a projected passenger volume for a particular corridor. Vehicle capacities in conjunction with service frequency are the primary factors that will help achieve a required volume of customers.

Table 12.2 summarises the various vehicle length options along with the associated passenger capacity. The actual passenger capacity depends upon a range of factors including interior layout, the number of seated versus standing passengers, and cultural norms regarding the space required per passenger.

12.1.2.1 Calculating the optimum vehicle size

The methodology for calculating the appropriate vehicle type in any given situation has already been put forward in Section 8.2 of this Planning Guide. Equation 12.1 summarises the principal calculation required to determine the optimum vehicle size.

Table 12.2: Vehicle options and passenger capacities

Vehicle type	Vehicle length (metres)	Capacity (passengers per vehicle)
Bi-articulated	24.0	240–270
Articulated	18.5	120–170
Tandem	15.0	80–100
Double decker	12–15	80–130
Standard	12.0	60–80
Midi-bus	6.0	25–35
Mini-bus (vans)	3.0	10–16

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

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

Equation 12.1 Determining required vehicle capacity

The so-called "optimum" vehicle size, though, may vary from corridor to corridor. One option is to operate different sized vehicles in different corridors of the city. However, this lack of commonality can be disadvantageous for several reasons. First, purchasing different vehicle types will tend to reduce economies of scale in procurement and lead to higher overall vehicle costs. Second, different vehicle types may require different maintenance needs and different sets of spare parts, and thus again undermining overall economies of scale. Third, managing a fleet of different vehicle types reduces operational flexibility in using vehicles in different corridors, especially when breakdowns and other maintenance requirements may take some vehicles offline for a period of time. Fourth, different sized vehicles means that station sizes will also need to vary, resulting in the possible inability of operating vehicles across multiple corridors in a single customer routing.

For all these reasons, it is typically preferred to choose a single vehicle type that can serve the spectrum of trunk line routes. Likewise, one or two smaller vehicle types can be chosen for the feeder services.

A common mistake involves assuming that larger vehicles are somehow "better". In truth, the best vehicle size is one that allows for a cost-effective operation and for the given volumes and service frequency. If a large bus requires ten minute headways between vehicles so that the optimum load levels can be achieved, then choosing a lower capacity vehicle might be more convenient. Passengers prefer headways in the range of one to four minutes. Long wait times will ultimately lead passengers to choose alternative modes of transport, such as private vehicles. It is important that the operational design include a preference analysis that studies time valuation by customers in such a way that the optimum vehicle type and fleet numbers can be chosen and that an appropriate quality level can be achieved with the allocated budget.

12.1.2.2 Bi-articulated, articulated, and standard-sized vehicles

High-volume systems (over 7,000 passengers per hour per direction) will likely require both

Fig. 12.3
In Curitiba, 24-metre bi-articulated vehicles are utilised on trunk corridors.
Photo courtesy of Volvo Bus Corporation

Fig. 12.4
In Bogota, 18-metre articulated vehicles are utilised.
Photo courtesy of TransMilenio SA

Fig. 12.5
In Brisbane, trunk corridors are served by standard 12-metre vehicles.
Photo courtesy of Queensland Transport

large sized (articulate or bi-articulated) vehicles and high-frequency service (Figures 12.3 and 12.4). Lower-volume systems should also strive for high-frequency service, but obviously with smaller vehicle types. Systems in Brisbane and Jakarta operate trunk corridors with 12-metre standard-sized vehicles (Figure 12.5). The smaller size does not mean these systems are inferior to cities operating with larger vehicles. Instead, the size may just be a reflection of the appropriate configuration for the particular demand characteristics.

While the numerous vehicle manufacturers offer a wide-range of options, consideration of market availability is also a key factor. Engaging in informal discussions with vehicle manufacturers at the outset can help highlight the availability of different product features. Clearly, the vehicle specifications should not be designed around any one manufacturer, but a broad understanding of the existing options from manufacturers can help shape the analysis.

Along the same lines, the number of manufacturers providing a particular vehicle type is a legitimate consideration. A single-sourced vehicle will tend to increase costs due to the lack of a competitive manufacturing environment. As an example, currently only one major manufacturer produces a bi-articulated vehicle. Thus, if this type of vehicle is chosen the bidding process is more likely to be less competitive. The lack of competition ultimately results in higher prices for operators, which will then translate into higher customer fares.

Fig. 12.6
In Hong Kong, the double-decker represents an iconic image for the city.
Photo courtesy of Volvo Bus Corporation

12.1.2.3 Double-decker vehicles

Increasing the length of the vehicle is just one way of increasing passenger capacity. Adding another passenger level with a double-decker configuration is another option that is occasionally utilised. Despite being less popular at a global level, double-decker have successfully created a niche market in such cities as Singapore, London, and Hong Kong (Figure 12.6).

To date, double-decker vehicles have not been utilised in a full BRT system. However, in the right circumstances, the double-decker vehicle can be an option to consider. Specifically, the double-decker has been successful in creating an iconic image for cities. Double deckers can generate an intriguing image to a public transport system and can be quite popular when applied to tourist routes, as the vehicle's upper deck offers a great vantage point for sightseeing.

Other arguments that support double-decker vehicles involves the fact that higher passenger density can be achieved while maintaining a low footprint density on the in-use road space. Thus, while an articulated vehicle gains passenger numbers by the length of the vehicle, a double-decker gains passenger numbers by its height. A double-decker vehicle will also consume less road space at stations.

However, double-deckers can bring many complications and additional costs. The costs of adding a second floor to the vehicle is not entirely devoted to customer space. A significant amount of space is consumed by the stairway on both decks of the vehicle. The stairway also creates potentially troublesome difficulties for passengers, particularly during boarding and alighting. Moving up and down the stairway as the vehicle moves can be dangerous. The width of the stairway also makes two-way passenger movement difficult. The net effect is dramatically lengthened passenger boarding and alighting times. London has phased out its iconic "Routemaster" in part due to the severe injuries and even deaths resulting from passengers falling from either the interior stairway or the back alighting step.

Double-deckers are also not particularly suitable for high-volume operations where passengers are frequently boarding and alighting. Double-deckers are best used on conventional commuter routes where most of the boarding and alighting takes

Fig. 12.7
Despite various operational limitations, double-decker models are still being sold in some markets, such as in Dhaka.
Photo by Lloyd Wright

place at a few station points in the centre of the city and then again at a distant suburban location.

Despite these disadvantages, some cities are still committing resources to double-decker vehicles. Due to enticements from a vehicle manufacturer, Dhaka (Bangladesh) has purchased double-decker models as part of its fleet (Figure 12.7).

Table 12.3 summarises the advantages and disadvantages of utilising double-decker vehicles within the context of BRT.

12.1.2.4 Floor height

After the physical length, the floor height tends to be one of the most crucial physical characteristics of the vehicle. The floor height will affect decisions on boarding and alighting strategies, customer convenience, vehicle costs, and maintenance costs.

In general, there are a full range of options including low floor, semi-low floor, and high-flow vehicles. With any of these options a level (step-free) boarding is possible. In fact, most of the well-known Latin American systems, such as Bogotá, Curitiba, Goiânia, Guayaquil, Pereira, and Quito, operate high-flow vehicles with platform level boarding.

Vehicle chassis tend to be produced in certain standard floor heights. Two of the most common interior floor heights are 20 cm (low-floor) and 90 cm (high-floor). There are also low-floor models with an interior floor height of less than 20 cm.

12.1.2.5 Manufacturing history

Bus manufacturing in most developing countries is still heavily reliant on high floor buses. High floor buses are a hold over from the days when buses were built by manufacturing bodies designed for passenger transportation and attaching them onto a chassis that was designed for hauling freight (Figure 12.8).

Table 12.3: Advantages and disadvantages of double-decker vehicles

Advantages	Disadvantages
Increases passenger carrying capacity without increasing road space footprint	Adds cost to vehicle; cost per passenger carried is much higher than articulated vehicles
Creates intriguing public transport image and is attractive for tourism	Stairway consumes passenger space on both floors and thus reduces overall passenger density in vehicle
	Can be dangerous for passengers using stairway while vehicle in motion
	Boarding and alighting can be delayed due to congestion on stairway
	Height of vehicle can be a problem on some routes with low-clearance infrastructure and trees
	Height of roof and the structural integrity of the roof creates difficulties in placing cylinders for natural gas or other alternative fuels

Fig. 12.8
Early buses were simply adaptations of freight vehicles, resulting in little customer convenience or comfort.
Photo courtesy of the Hank Suderman Collection

Fig. 12.9
A new CNG modelled low-floor vehicle developed by Tata Motors for the Dehli BRT system.
Photo courtesy of Tata Motors

The first buses had major drawbacks in terms of user comfort and safety, as suspensions and braking systems were designed to transport loads of cargo, not people. The engine's frontal location created loud noise levels inside the vehicle and did not allow for interior space optimization. Most of the vehicles also rode very high on the chassis, requiring passengers to climb up a steep set of stairs to enter the bus.

All these reasons led to the development of chassis, suspensions, and engines designed specifically for passenger services, which in turn improved comfort and safety conditions. The new generation of vehicles utilised metallic spring suspension systems, and engines were mounted in the rear. However, its passenger platform remained at 90 cm, so inconvenience and delay for passenger boarding continued.

At the end of the 1990's, a third generation of buses was developed: namely, low-floor vehicles whose principal objective was reducing the passenger platform's height in order to optimise access to the vehicle (Figure 12.9). Presently, the majority of these vehicles have integral structures, rather than an independent chassis and body, which has allowed for the development of hydraulic suspension systems and engine options which allow for interior space optimisation.

12.1.2.6 Low-floor versus high-floor vehicles

From the perspective of BRT systems, the debate over low-floor versus high-floor is somewhat secondary to the preference for platform-level boarding and alighting. Steps of any type will slow dwell times as well as make a system off-limits to the many of the physically disabled. Even low-floor vehicles will slow boarding times as well as create a usage barrier to persons in wheelchairs.

Either low-floor vehicles or high-floor vehicles can be adapted for usage with platform-level boarding. Attempting to operate stepped boarding and alighting in high-volume operations can be detrimental to system performance, regardless of floor height. The Transantiago (Santiago, Chile) system elected to operate low-floor

Fig. 12.10 and 12.11
Low-floor vehicles without platform level entry and pre-board fare verification can result in longer dwell times and not actually provide access to the physically disabled, as shown in these images from Santiago (left photo) and Brisbane (right photo).
Left photo by Lloyd Wright
Right photo courtesy of Queensland Transport

Fig. 12.12
In European cities, such as London, low-floor vehicles provide an improved image for conventional bus systems.
Photo by Lloyd Wright

(20 cm) vehicles without platform level boarding. In conjunction with the decision to have on-board fare verification, the result has been serious station delays (Figure 12.10). Likewise, the Brisbane system also combines low-floor vehicles and on-board fare verification (Figure 12.11). While these types of systems may provide an adequate service, they cannot match the operational performance levels of cities utilising platform-level boarding.

Low-floor vehicles have predominantly been deployed in conventional bus systems in developed nations in Europe and North America (Figure 12.12). These systems generally operate without closed stations, platform level boarding, or pre-board fare verification. In such cases, low-floor vehicles provide a somewhat better physical image and make boarding easier in comparison to high-step entry.

As low floor bus technology becomes more affordable and widely available in developing countries, it has become a matter of debate whether new BRT systems should be designed for use with high- or low-floor vehicles, and whether the high BRT platform is necessary or desirable.

The principal advantages of low-floor vehicles relate to the physical image of the vehicles as well as some aspects of operational flexibility. The principal advantages of high-floor vehicles relates to the procurement and maintenance costs of the vehicles (Figure 12.13). Further, high-floor vehicles in conjunction with platform-level boarding actually offer faster dwell times and greater access for the physically disabled than low-floor vehicles without platform-level boarding.

Low-floor vehicles offer greater operational flexibility since the vehicles can operate with and without boarding platforms. For BRT systems where the vehicles are likely to operate both on trunk corridors and in mixed traffic conditions where no boarding platforms will be available, the low floor height helps increase passenger boarding and alighting speeds during the curbside boarding sections of the route. System planners in India pushed strongly for low-floor vehicles in the hope that the BRT project would force the Indian bus industry to innovate and provide low-floor vehicles for conventional (non-BRT) services as well.

Fig. 12.13
High-floor vehicles in conjunction with platform-level boarding has been the cost-effective solution for most high-quality systems in Latin America, such as the system in León.
Photo courtesy of Volvo

In instances where the trunk vehicle operates with two-sided doorways, the low-floor design can ease internal vehicle movements for customers. If a vehicle operates with high-floor on one-side (median station) and low-floor on the other (curbside), then there will be steps inside the vehicle. This configuration is utilised in Porto Alegre. By contrast, if a low-floor design is utilised, then there will be no internal steps since both the median and curbside doorways would be at the same level. Also, by avoiding the need for any steps inside the vehicle, space for seating is saved.

Low-floor vehicles can also be preferred for aesthetic and urban design reasons. The 70 cm difference in floor height means that the station height is reduced by 70 cm. This height reduction can help to mitigate concerns over roadway severance. The lower height will also marginally reduce the construction cost of the stations since

Table 12.4: Comparison between high-floor and low-floor vehicles

Factor	High-floor vehicle	Low-floor vehicle
Purchase cost	Lower purchase costs	More complex chassis results in a purchase cost approximately 20% to 30% higher than high-floor vehicles
Maintenance cost	Distance from roadway impacts reduces maintenance costs	Higher maintenance costs (10% to 20%) due to proximity to roadway imperfections
Station costs	Somewhat higher (5%) station costs due to the higher base	Somewhat lower station costs
Urban design aesthetics	Station profile will be 70 cm higher	Station profile will be 70 cm lower and thus will somewhat reduce visual severance
Customer convenience	High-floor vehicles with platform-level boarding eases boarding and alighting for everyone	Same as high-floor if platform-level boarding is used; otherwise, the step will make wheelchair entry difficult
Vehicle towing	In case of breakdown high-floor vehicles can be towed by a conventional tow truck	Many low-floor vehicles require a special type of towing vehicle
Fare evasion	Provides a better natural defense against fare evasion	More susceptible to fare evasion
Vibrations	Higher suspension somewhat reduces roadway bumps and vibrations	Somewhat more susceptible to roadway vibrations and thus making reading potentially more difficult
Seating	Less impact on seating arrangement from the wheel-wells	Some impact on the height and number of seats due to the wheel-well

the concrete base of the station will be reduced by 70 cm.

However, low-floor buses have their drawbacks. Being closer to the ground, the buses typically incur more structural stress and thus have higher maintenance costs. Road surfaces must be maintained at a very high level for low-floor bus routes in order to avoid and minimise any potential vehicle damage. This is a particularly serious issue in developing countries. These problems will be made worse if flooding is a risk along the BRT corridor. Small imperfections in the road surface will also tend to make the ride less smooth and comfortable for the users.

Low-floor vehicles have somewhat lower passenger capacity in comparison with high floor vehicles because the wheel-wells encroach on the passenger seating area. Standard tow trucks are not always able to move low-floor vehicles when there are mechanical problems, so specialised towing vehicles are required.

Low-floor vehicles also somewhat complicate preventing fare evasion. With a ramped-entry high-floor vehicle, the height of the platform acts as a natural barrier against individuals trying to enter from outside the station. With low-floor vehicles, fare evaders can sneak between the station and the bus, and then enter the vehicle with relatively little difficulty.

Low-floor vehicles also typically cost 20 to 30 percent more than standard models. Manufacturing low-floor vehicles requires the use of modern manufacturing technology, which is not always available in developing countries. In some cases, this means that the use of a low-floor vehicle will affect whether the vehicles can be assembled locally or will need to be imported, and thus have a significant impact on the cost of both procurement and maintenance.

Table 12.4 summarises the various trade-offs between high-floor and low-floor vehicles.

12.1.3 Interior design

"Art has to move you and design does not, unless it's a good design for a bus."

—David Hockney, painter and designer, 1937–

From a customer perspective, the interior of the bus is far more important than the mechanical components propelling the bus. The interior design will directly affect comfort, passenger capacity, security and safety.

A basic starting point for developing the interior design is to determine the amount of seated and standing space in the vehicle. The amount of space dedicated to standing areas and to seated areas will be based upon expected passenger flows, especially accounting for peak capacities. In general, customers will have a preference for as much seating as possible. However, the operational economics of the system may require a certain number of standing passengers, especially during peak periods, in order to deliver an affordable fare.

A sharp peak period will tend to force a greater number of standing customers. However, there are also other considerations. If travel distances are relatively long in the city (*e.g.,* an average trip distance over 15 kilometres), then it will be quite tiring for customers to be standing. By contrast, if average trip distances are relatively short (*e.g.,* under 5 kilometres), then standing is less of an issue (Figure 12.14 and Figure 12.15).

However, even in cases of relatively short trip distances, the value of a seat to a customer

Fig. 12.14 and 12.15
In cities, such as Quito and Bogotá, with relatively short average trip distances, there can be more tolerance for having many standing passengers. In cities with long travel distances, it can be quite tiring to customers.

Left photo by Lloyd Wright
Right photo by Carlos F. Pardo

Fig. 12.16
Customers in Bogotá make their own seating on the floor of the vehicle. Every effort should be made to maximise seating to the extent possible.
Photo by Carlos F. Pardo

should not be underestimated. After a day of work or school, many patrons are not pleased to stand for even a few kilometres (Figure 12.16). Every effort should thus be made to provide sufficient seating and/or manage operations to minimise standing.

A standard 18-metre articulated vehicle may have anywhere from 40 to 55 seated passengers, depending upon the seating and doorway configuration. With more doorways, there will be less space for seating. The width of aisle ways will also be part of this equation. To lessen the discomfort of standing, quality holding devices (poles, straps, etc.) should be provided.

Seating facing to the sides rather than to the front can be effective in opening up space for standing passengers (Figure 12.17). Front-facing single seats can also be preferred by customers who wish to maintain a degree of privacy. Double seats can create difficulties when customers prefer the aisle seat in order to be more accessible to the exit. In such circumstances, other customers must step over the aisle-seated customer to access the window seat. In other cases, customers may place belongings on one of the double seats in order to prevent others from sitting alongside. These circumstances can create conflicts between customers. Instead, good design practices should be employed to avoid potentially awkward customer situations.

Fig. 12.17
Side facing seating, as shown in this example from Jakarta, will tend to maximise space for standing passengers and thus such a configuration will aximise overall passenger capacity per vehicle.
Photo by Karl Otta, courtesy of the GTZ SUTP Photo CD-ROM

The vehicle's internal layout must comply with legal restrictions and must also consider the number and location of doors in the vehicle, in such a way that internal circulation, handicap access, and access at stops is readily available in the least amount of time possible.

An 18-metre articulated vehicle will typically have either three or four sets of double doorways. There is a trade-off with each configuration. With only three doorways, there will be more space for seating. However, four doorways are considerably more efficient in allowing rapid boarding and alighting (Figure 12.18). As always, much depends on the local context to determine which trade-off is the most important.

Special arrangements should also be made to cater to the needs of physically disabled and elderly passengers. The station entry ramps are an important feature, but likewise adequate interior space for wheelchairs is key. Additionally, the safe attachment of wheelchairs to a fixed interior structure may be required. Space for wheelchairs can also double as standing capacity during peak periods (Figure 12.19).

Bicycles can also be safely and effectively secured inside the bus. Unfortunately, the bicycle is needlessly banned from many bus systems. With the ramped entryways of BRT vehicles, bicycles can be easily boarded, especially during non-peak periods. The space permitted for bicycles can also be an effective open space for standing passengers during peak times. BRT

Fig. 12.18
Bogotá utilises a four door configuration that helps to reduce boarding and alighting times.
Photo courtesy of TransMilenio TM

Fig. 12.19
Space allocated for special needs passengers, such as those with wheelchairs, can also be useful in meeting standing capacity during peak periods.
Photo by Lloyd Wright

vehicles in Rouen (France) provide this type of open area for easy bicycle entry (Figure 12.20).

In typical conditions, a seated passenger consumes as much as twice the space as that required by a standing passenger. However, the amount of personal space each passenger requires can vary between different cultures. In Latin America, it is somewhat acceptable to tolerate relatively packed conditions. Knowledge of local preferences in conjunction with stated preference surveys can help evaluate the best spatial arrangement. The interior of the Bogotá TransMilenio vehicles is designed to a standard of as many as 7 passengers per square metre. In other cultures this level of crowding would be completely unacceptable.

The type of seating can greatly affect customer comfort. Cloth and padded seating offers additional comfort to passengers (Figure 12.21). However, there are cost and maintenance issues to consider with these types of seats. While plastic seating is not as comfortable, such seating is less costly and is easier to clean and maintain.

Special panoramic windows allow better views of the external environment. Panoramic windows offer a larger visible area for customer views (Figure 12.22). Being able to see upcoming stations and station name plates is especially important for customers unfamiliar with a particular

Fig. 12.20
In cities such as Rouen (France), space is provided to allow bicycles to be taken directly onto the vehicle.
Photo by Graham Carey

Fig. 12.21
Cloth seating can greatly enhance the customer experience.
Photo courtesy of Advanced Public Transport Systems

Fig. 12.22
Panoramic windows, as in this bus in Aichi (Japan), can dramatically improve the customer's ability to see the outside environment.
Photo by Lloyd Wright

corridor. Clean and highly visible windows also make the journey more enjoyable for passengers who wish to view of the outside environment.

The aesthetic design of the interior can also affect the customer's opinion of the system. As shown in Figures 12.21 and 12.22, the right choice of shapes, colours, and textures can all do much to create a professional and friendly environment.

12.1.4 Environmental performance

"The system of nature, of which man is a part, tends to be self-balancing, self-adjusting, self-cleansing. Not so with technology." (Small is Beautiful)

—E.F. Schumacher, economist, 1911–1977

In addition to complying with the governing legislation, the project must define its minimum environmental standards. Because of the profitability of BRT, it is usually possible to set a higher environmental standard on BRT vehicles than is required under the law without compromising the profitability of operations. As BRT projects play an important role in improving environmental conditions, raising environmental standards as high as can be financially sustained is generally recommended.

Generally, the following must be considered in assessing the environmental quality of a system:

- Emission levels;
- Ambient air quality standards;
- Fuel quality;
- Fuel type and propulsion system;
- Levels on interior and exterior noise;
- Ventilation and temperature standards (air renewal/time unit).

In the needs assessment of the project, it is important to set the environmental goal. From an emissions standpoint, there is no one clear technical solution that is necessarily superior to another. Each fuel carries with it different trade-offs of costs, emissions, infrastructure, and potential operating constraints. In some instances, a fuel may emit less of one type of pollutant but more of another type of pollutant. Much will also depend on the availability of a particular fuel. For example, CNG may do well in terms of reducing particulate emissions, but its life-cycle greenhouse gas emissions may not offer a significant advantage over diesel technology.

Some fuels may produce less local emissions but may produce significant emissions at the point of electricity generation. Some fuels may produce few emissions from the standpoint of fuel tank to wheels but can produce significant emissions when the full fuel cycle is considered (*e.g.,* well to wheels). For example, electric vehicles and hydrogen-fuelled vehicles may produce zero emissions at the tailpipe, but the emissions generated at the power-plant or through the hydrogen generation process can be quite substantial. Some fuels may work well in ideal conditions but are more polluting in circumstances when maintenance and road conditions are poor, or at high altitudes.

12.1.4.1 Emission standards, fuel quality, and ambient air standards

Emission standards

Emission standards are the most typical mechanism for differentiating between the emissions levels of different options. The standards set forward by the US Environmental Protection Agency (US EPA) and the European Commission are most typically used to classify emission performance of different technologies. Figure 12.23 gives an indication of how European and US EPA standards are related in terms of NOx and PM emissions. For the most part, the two systems follow similar long-term objectives, although there are a few differences.

In many developing nations, the "Euro" (*i.e.,* European) standards are being applied. Table 12.5 provides more detail on the Euro emissions standards along with the likely fuel and technology requirements.

In order to achieve desired emissions standards or reductions from existing buses, several different components of the emissions control program must be taken into account including:

- Fuel quality;
- Engine technologies;
- Emission-control technologies;
- Inspection and maintenance program; and
- Driver training.

A strategy incorporating each of these components will be most effective (Figure 12.24). In order to ensure the greatest possible emissions reductions from both the new vehicles and the existing fleet a comprehensive emissions-control programme will be required.

In determining the appropriate emissions standards and technologies within a specific city or fleet perspective, many considerations must be taken into account, including the reliability of the fuel supply to meet quality standards, the mechanisms and incentives are in place to

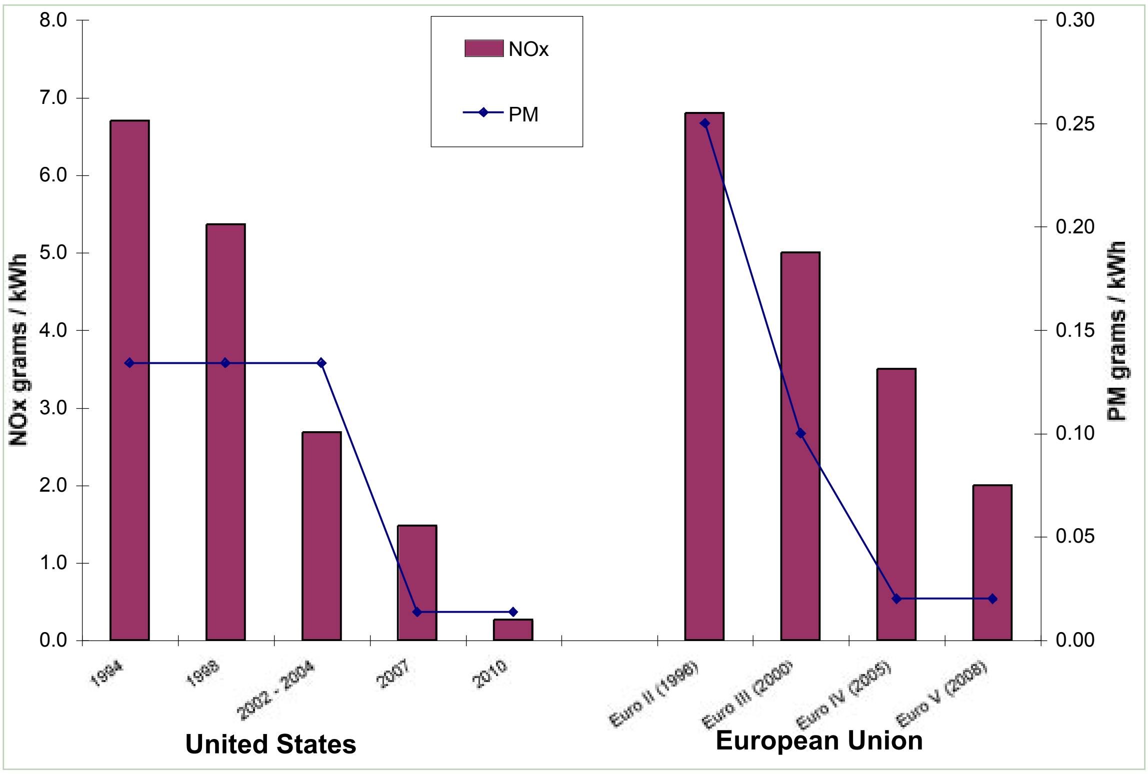


Fig. 12.23
NO_X and PM standards for heavy-duty trucks and buses in the US and Europe.

Table 12.5: Euro emission standards for heavy vehicles

Level	CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	PM (g/kWh)	Certification fuel sulfur content (ppm)	Likely technological requirements
Euro I	4.5	1.1	8.0	0.612	2,000	Higher pressure fuel injection for PM control, timing retard for NO_x control.
Euro II (1996)	4.0	1.1	6.8	0.25	500	All engines are turbocharged, improved high pressure fuel injection and timing optimisation.
Euro III (2000)	2.1	0.66	5.0	0.1	350	In addition to above, electronic control for fuel injection, timing retard for NO_x, common rail (CR) fuel injection, some exhaust gas recirculation (EGR).
Euro IV (2005)	1.5	0.46	3.5	0.02	50	In addition to the above, further NO_x reduction using EGR or selective catalytic reduction (SCR). Some systems will use diesel particulate filters (DPFs) and most will incorporate oxidation catalysts.
Euro V (2008)	1.5	0.46	2.0	0.02	10	Similar to above, with more reliance on SCR.

Source: CITEPA, 2005

ensure follow-up and compliance with driver training and maintenance procedures, and the applicability of the technology in context to the operating conditions of the fleet. Each component has a different ramification in the developing-nation context. Can the quality of the incoming fuel be assured and how will adulteration of fuels be avoided? If advanced engine and emission-control technologies are utilised, how robust are these technologies in developing city conditions? If an improved driver and maintenance programme is established, what mechanisms and incentives are in place to ensure follow-up and compliance?

Fig. 12.24
Technology is not the only solution to ensuring low emissions, as maintenance, fuel quality, and driving habits all contribute to the actual emission levels.
Photo by Lloyd Wright

In addition to emission standards, system planners may also specify the maximum allowable age of buses operating on the system. The age specification will help to maintain long-term system quality as well as ensure all private operators are competing on an equal basis. The maximum age will also play a fundamental role in calculating the operator's amortisation rate for the vehicle.

Fuel quality

In a BRT project, it is fairly typical that the BRT authority has control over the vehicle standard but only limited influence on the fuel standard and fuel availability. However, in several cases a BRT project has been used to pressure the energy companies to provide cleaner fuels. The additional operational controls within a BRT system may make it possible to ensure a higher-quality fuel supply than is available within the rest of the city and should make it possible to reduce the problems of fuel adulteration. In any case, the technical specification has to be set with awareness of available fuel quality. In Ecuador, the city of Quito maintains higher-fuel quality standards than other cities in the country. This higher level is in part due to the city's unique climatic and geographical conditions (2,800 metres of elevation) as well as the presence of a BRT system.

It is generally best to set the minimum allowable vehicle emission standard without specifying a specific technology, as this gives the operator greater flexibility to consider a range of factors such as fuel costs, fuel availability, maintenance, reliability, refuelling times, and performance when complying with the standard. These factors will vary by location and situation, and the private sector may be in the best position to weigh the relative economic value of each factor. For instance, in Bogotá, the BRT authority specifies that buses must meet a minimum Euro II emission standard and have set forward a schedule to move towards Euro IV standards. TransMilenio does not specify a particular fuel or propulsion technology. These decisions are left to the private operators. There are also incentives in place for operators to propose vehicles exceeding the minimum standard. Such operators receive more points during the bidding process.

Fig. 12.25
On the Quito Central Norte corridor, the Euro III compliant vehicles are not producing the desired results due to the use of 500 ppm diesel fuel.
Photo by Lloyd Wright

For BRT, the cleanest new vehicles that are compatible with available fuel quality are generally advisable. In some cases, BRT systems have been operated with a mismatch between the vehicle technology and the available fuel (Figure 12.25). Somewhat cleaner vehicles may be able to cope with dirtier fuels but may face increased maintenance issues. While Euro II and III vehicles are generally more forgiving than Euro IV or V vehicles, higher sulphur levels than are found in certification fuels may still increase maintenance costs for sensitive electronic engine equipment, such as high pressure or common rail fuel injection. Lower sulphur fuels will reduce maintenance costs and improve vehicle durability for all vehicles, regardless of emissions standard.

Fig. 12.26
All public transport vehicles in Delhi, including the oldest vehicles, faced a mandatory conversion to CNG fuel in order to overcome difficulties with adulterated fuels.
Photo by Lloyd Wright

However, in some instances, there may be reason to specify a particular fuel type. In Delhi (India) all public transport vehicles have been mandated to utilise compressed natural gas (CNG) as fuel (Figure 12.26). In order to improve profits, some fuel suppliers in India mix kerosene, which is subject to much lower taxation rates, into the diesel. The result is poor performing vehicles, higher emissions, and more costly maintenance requirements. Thus, requiring Euro II or Euro III technology can be meaningless in such a scenario since there is little control on the input fuel. By contrast, it is quite difficult to adulterate CNG and thus its quality is more assured. Despite the rationale of this course and the relative availability of CNG in India, Delhi's conversion from diesel fuels to CNG has been fraught with conflicts and political recriminations. Ultimately, it required the intervention of the national Supreme Court to intercede and ensure that the conversion process was finally undertaken.

Ambient air quality standards

Some cities also have ambient air quality standards, which can be used as a tool in driving improved environmental performance for vehicles. Though rarely enforced in developing countries and generally not linked directly to the transportation system, air quality standards could provide justification for cleaner fuels and more stringent emissions standards for a new bus fleet. If the air in a particular location is unhealthy and hence in violation of an ambient air standard, then there can be stronger justification for subsidising a cleaner bus technology.

Normally, if ambient air standards are in place and there are on-going violations of the standard, the responsible government agency will have an obligation to develop an air quality mitigation plan that will outline a step-by-step for resolving the problem. A clean vehicle standard can be an important part of such a mitigation plan.

12.1.4.2 Fuel types and propulsion systems

Many governments and promoters of clean technology rightly see BRT as a possibility for introducing cleaner vehicle technology. Because of BRT's profitability, it creates the potential of having a much cleaner vehicle without undermining the profitability of the service. However, this profitability is case specific, and clean technologies should not be forced on BRT systems without first assessing the impact the technology will have on the quality of service, the profitability of the system, the transparency of the vehicle procurement process, and other factors.

The choice of fuel and propulsion technology will have a profound impact on operating costs, maintenance costs, supporting infrastructure, as well as emission levels. Local circumstances play a central role in fuel choice as the availability of a fuel and experience in maintaining a particular vehicle technology are key factors. Further, as attention focuses more and more on the human and environmental costs of both local pollutants and global climate change, system developers are under increasing pressure to deliver cleaner vehicles options.

The following is a list of some of the most common fuel options currently being considered for public transport vehicles (Figure 12.27):

- Standard diesel;
- Clean diesel;
- Compressed natural gas (CNG);
- Liquid petroleum gas (LPG);
- Electric trolley-bus;
- Bio-diesel;
- Ethanol;
- Hybrid-electric (diesel-electric and CNG-electric);
- Hydrogen (fuel cell technology).

A range of other possibilities also exist such as fly-wheel technology, di-methyl ether (DME), and blended fuels (*e.g.,* water-in-oil emulsions).

Choosing the type of engines that will be purchased and the fuel that will be used requires that consideration be given to several important issues. The following factors are the most important when considering a fuel and propulsion technology:

- Fuel availability and price volatility;
- Vehicle cost;
- Reliability;
- Government policy;
- Environmental Impact.

Clean diesel

Clean diesel is a technology that both produces relatively low emissions and also is within the technology experience of most developing

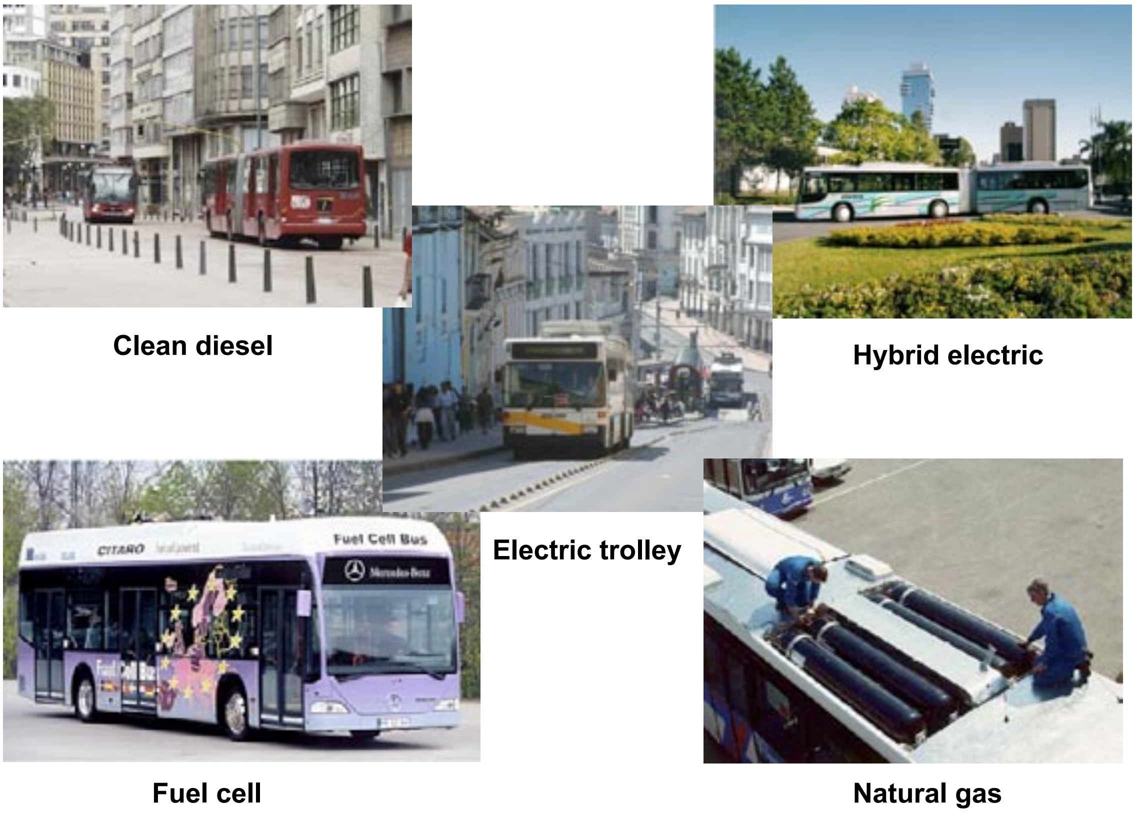


Fig. 12.27
Fuel and propulsion system options

cities. A "clean diesel" system implies that the propulsion system technology and the fuel quality are such that the end result is much lower emissions than a standard diesel vehicle. The International Energy Agency notes that (IEA, 2002b, p. 61):

> "Diesel engines are recognised and favoured worldwide for their fuel efficiency, excellent durability and low maintenance requirements. They offer the convenience of using a liquid fuel that is easily dispensed through an established fuelling infrastructure. The technology is mature, widely produced and competitively priced. Although diesel engines have historically produced high levels of pollutant emissions, especially oxides of nitrogen (NO_X) and particulate matter (PM), recent improvements in engines, fuel and emissions-control technology have resulted in new diesel systems for buses that are substantially cleaner than they were only a few years ago."

For diesel, sulphur content is the most critical factor to consider, as many of the pollution control devices used in the cleaner buses require lower sulphur fuels. In some developing cities, diesel fuels may contain over 2,000 parts per million (ppm) of sulphur. To achieve Euro II standards, a sulphur level of less 500 ppm is likely to be required. To achieve "ultra-low-sulphur diesel" (ULSD), the fuel must contain less than 50 ppm. Many emission-control technologies will only function properly if the fuel sulphur levels are below acceptable levels.

Reducing sulphur from diesel fuel also carries with it other emissions benefits, such as simultaneously also reducing particulate matter (PM), which is a key pollutant from a public health perspective. As shown in Figure 12.28, sulphur contributes to the production of particulate matter in all diesel engines. At higher sulphur levels, sulphate can account for up to 5 to 15 percent of PM emissions from diesel. At lower sulphur levels, after-treatment emissions controls can reduce PM emissions much more substantially, either as retrofit devices or as standard equipment on new vehicles meeting more stringent standards. Diesel oxidation catalysts, which can reduce PM emissions by 20 percent to 30 percent, can generally be used with sulphur levels up to 500 ppm. Diesel particulate filters, which can reduce more than 90 percent of PM emissions, generally require sulphur levels to be under 50 ppm.

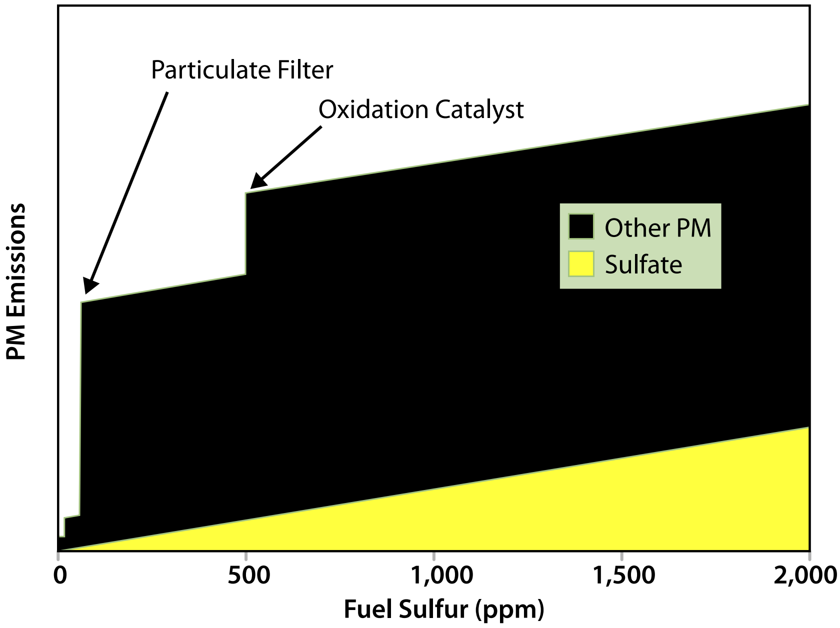
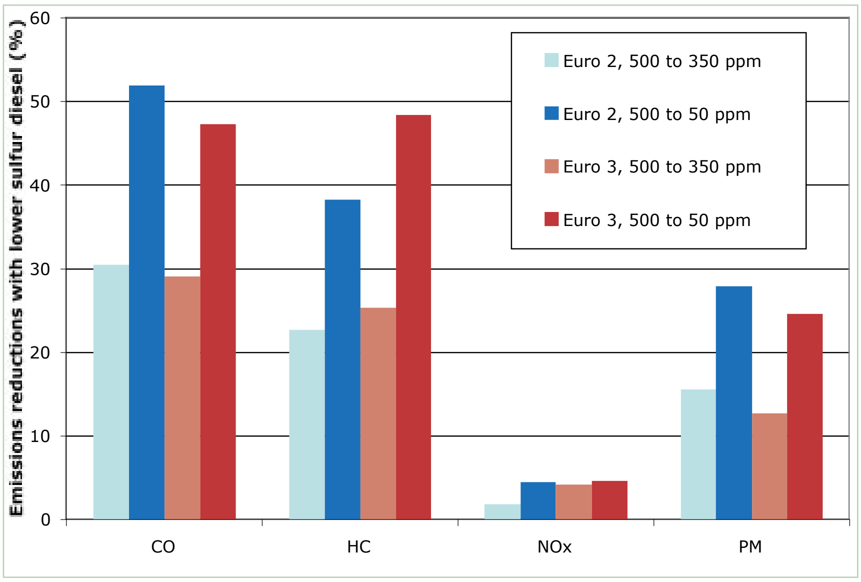


Fig. 12.28
There is a close relationship between the emissions of sulphur and emissions of particulate matter (PM).

Fig. 12.29
Size of possible emissions reductions with lower sulphur fuel (Wangwongwatana, 2003).



Hydrocarbons (HC), carbon monoxide (CO), and even nitrogen oxides (NO_X) are also impacted by emissions standards and contingent on fuel quality. As can be seen in Table 12.5, the Euro standards are scheduled to reduce emissions of all major pollutants. Euro II and III each represent a 60 percent reduction in PM emissions from the previous standards (Figure 12.29). Euro IV standards have 80 percent lower PM emissions than Euro III, and thus representing a 97 percent reduction from Euro I standards. The cleaner the vehicle, however, the more sensitive it is to fuel quality.

Emissions from diesel vehicles will vary depending on local conditions such as altitude, atmospheric pressure, humidity, and climate. The quality of ongoing vehicle maintenance and the integrity of the fuel supply chain will also affect specific system emissions. Nevertheless, with the right fuel quality, diesel vehicles can produce emissions reductions in line with many of the more costly alternative fuels. In general, it can do so with a lower vehicle cost and with a more robust maintenance regime.

Compressed natural gas (CNG)

CNG is highly touted as a reliable fuel option that "inherently" achieves lower emissions. CNG contains virtually no sulphur and naturally burns quite cleanly. However, CNG is not a perfect solution. For some emission types, the performance of CNG may not be that much better than clean diesel vehicles.

In the case of greenhouse gas emissions, the entire well-to-wheels analysis of CNG production, distribution, and use may imply that there is little, if any, advantage over diesel. Upstream methane losses along pipelines can significantly increase total life-cycle greenhouse emissions for CNG. Some studies estimate that with the inclusion of methane leakage, CNG will actually produce significantly more total greenhouse gas emissions (CVTF, 2000).

There are also other issues to consider with CNG. The low energy density of the fuel means that the gas must be compressed for on-board storage in large, bulky cylinders. CNG vehicles also require different maintenance skills that may not be common in developing cities. In some cases, CNG vehicles may face power issues on steep hills, at high altitudes, and in some temperatures. The refuelling infrastructure for CNG can also be costly to develop. Refueling time is also a consideration. The amount of time required for refuelling is also an issue for CNG vehicles. Typically, refuelling time per vehicle will range from 20 minutes to 40 minutes.

Nevertheless, CNG holds much potential for emission reductions of PM and SOx, and thus, if the fuel is available locally, then the technology should be given serious consideration. Further, as experience grows with CNG, the technology is becoming increasingly robust from a maintenance standpoint.

Fig. 12.30
Los Angeles has developed the infrastructure to utilise CNG technology for the entire fleet on its Orange Line.
Photo courtesy of the Los Angeles County Metropolitan Transport Authority

Electric-trolley vehicles

Electric-trolley vehicles are a well-established technology that produces zero emissions at the point of use. The total fuel-cycle emissions of electric-operated vehicles will depend upon the fuel used in the electricity generation. Fossil-fuel based electricity generation, such as electricity from coal or petroleum, will produce high levels of total emissions, while renewable sources, such as hydro-electric and wind sources, will be relatively emission free. Thus, in countries with clean electricity generation, electric trolleys can be a low-emitting option to consider. Electric-trolley vehicles are also extremely quiet in operation. Table 12.6 summarises the different issues to consider in choosing electric-trolley technology.

Biofuels (ethanol and bio-diesel)

Ethanol is a fuel produced from the fermentation of sugars in carbohydrates, derived from agricultural crops like corn and grains, wood, or animal wastes. Currently, ethanol is derived predominantly from corn and sugar cane (Figure 12.31). Brazil possesses an extensive ethanol programme using sugar cane. In the future, cellulosic ethanol may become viable, in which the fuel can be derived from a broader range of plant and agricultural species. However, commercial production of cellulosic ethanol is yet to be fully realised.

Bio-diesel is a fuel derived from biological sources that can be used in diesel engines

Fig. 12.31
Sugar cane production in Mauritius.
Photo by Lloyd Wright

Table 12.6: Advantages and disadvantages of electric-trolley technology

Advantages	Disadvantages
Zero emissions at point of use (total emissions will depend on fuel type for electricity generation)	Vehicles can cost up to three times the amount of a comparable diesel vehicle
Quiet operation	Operating costs highly dependent on electricity prices; subsequent electricity deregulation can destabilise financial model
Smooth ride characteristics	Route modifications are very expensive
Longer vehicle life (up to twice the vehicle life of diesel vehicles)	Longer implementation time required to build the electric conduit network
	Risk of service disruption during power failure unless vehicles have backup diesel motor
	Infrastructure costs can be over twice that of a non-trolley BRT system
	Presence of wiring, posts, and transformers can create aesthetic concerns, particularly in historical centres

instead of petroleum-derived diesel. Through the process of trans-esterification, the triglycerides in the biologically derived oils are separated from the glycerin, creating a combustible fuel. Bio-diesel fuel is currently derived predominantly from soya.

Biofuels hold the potential to deliver a product with net zero greenhouse gas emissions. The CO_2 emitted by biofuels can be balanced by the CO_2 absorbed during plant growth, potentially resulting in a fixed carbon cycle. However, the reality is more complicated. Total greenhouse emissions from biofuel production are still quite poorly understood including certain factors that could increase net greenhouse gas emissions considerably. These factors include: 1. Energy inputs into the cultivation of crops; 2. Secondary emissions that have climate change impacts (*e.g.,* black soot); 3. Amount of fertilizer use and resultant emissions of nitrous oxide (N_20); 3. Amount of pesticide use; and, 4. Type of biomass being displaced by energy crops. In some instances, such as soy-based fuels, the resulting greenhouse gas emissions from nitrogen releases may overwhelm other benefits (Deluchi, 2003). Additionally, it is unclear if the amount of agricultural land is sufficient to produce biofuels in a quantity sufficient to dramatically offset petroleum fuels (IEA, 2004b).

Biofuel production may have an array of other unintended side effects. As the market for biofuel builds, there will be growing pressure on sensitive eco-systems to be converted into crop production. This phenomenon is already clearly evident in the Amazon region of Brazil, where increased demand for soya is leading to further illegal destruction of the Amazon ecosystem. Each year, approximately 20,000 square kilometres of the Amazon rainforest are cleared for agricultural use (Economist, 2006b). More intensive biofuel production can also imply greater depletion of input resources such as soil quality and water (Figure 12.32).

There is also increasing concern over the impact biofuel production will have upon food prices. It is reported that the grain required to fill the typical 95-litre petrol tank of a sport utility vehicle with ethanol will feed one person for a year. The grain to fill the tank every two weeks over a year will feed 26 people (Brown, 2006). In the US, the amount of the corn (maize) crop dedicated to ethanol production increased 34 percent from 2006 to 2005. In 2006, some 54 million tons of maize went to ethanol production, even though ethanol only represents a small percentage of the fuel used in US vehicles (Planet Ark, 2006). In late 2006, an increase in maize prices due to biofuel demand caused tortilla prices to triple in Mexico. Since tortillas represent the staple of the local diet, many low-income families were severely affected by these increases. With strong protests from the population, the government was eventually forced to adapt price controls. These types of conflicts may become more common as the market for biofuels expands.

Fig. 12.32
The growing demand for soya has fuelled further destruction of the Amazon rainforest.
Photo courtesy of iStockphotos

Fig. 12.33
As the demand for biofuel increases, production inputs, such as water, will also come under increasing demand.
Photo by Lloyd Wright

Hybrid-electric vehicles

Hybrid-electric vehicles will likely be the one of the first of the advanced technologies to gain large-scale acceptance in the market. Hybrids utilise both conventional fuels (*e.g.,* diesel, CNG) and electrical motors to propel the drive-train. Electric power can be generated during vehicle deceleration and then utilised to operate motors attached to each wheel. Since electric motors are used for part of the vehicle's operation, hybrids offer superior fuel economy, reduced emissions, and lower noise levels (Figure 12.34.

However, even with this technology, the emission reduction benefits can vary depending on the driving duty cycle. The city of Seattle (USA) has made one of the largest investments in hybrid-electric technology within its bus system. However, despite manufacturer claims of fuel efficiency gains of 25 percent or more, the initial results in Seattle were significantly less due to the route choice (Hadley, 2004). If the bus duty cycle does not involve sufficient stop and go travel, then the efficiency gains from regenerative braking are not realised. The additional weight of the hybrid-electric vehicle offsets the gains from the on-board electricity generation (Wright and Fulton, 2005).

Like all new technologies, a certain period of adjustments and experimentation are required prior to optimum results being achieved. However, the complexity of propulsion system and cost of the hybrid components means that hybrids may not be well-suited for all developing city applications.

Currently, efforts are being made to produce hybrid-electric vehicles in Brazil. Because of various local conditions, such as lack of driver familiarity with the technology, the environmental benefits have been less than anticipated, but the problems are likely to be resolvable.

Fuel-cell technology

National research and development budgets have heavily invested in fuel-cell technologies. In 2003, the United States launched its five-year Hydrogen Fuel Cell Initiative with a commitment of US$1.7 billion in research funding. Likewise, the European Union is supporting a €2.8 billion (US$3.7 billion) public-private partnership in a ten-year fuel cell development programme. In 2003, Japan dedicated US$268 million of its government research budget to fuel cells. Likewise, other governments such as Canada and China also have their own fuel cell programmes (Science, 2004).

Fig. 12.34
The potential of hybrid-electric vehicles to cost-effectively reduce tailpipe emissions has drawn the attention of most manufacturers.
Photo courtesy of Volvo

Fuel-cell vehicles are under going testing in both developed and developing cities. Through a grant from the Global Environment Facility (GEF), several developing cities, such as Beijing and Cairo, have had an opportunity to evaluate the technology. However, none of these cities are actually operating full fleets with these technologies. The costs, environmental benefits, and performance of these vehicles are not entirely proven. Since most hydrogen is currently produced from electrolysis, the emissions benefits are directly tied to the type of technology utilised for the generation of the electricity.

The IEA notes that there are no certainties when hydrogen fuel cells will become commercially viable (IEA, 2004b). Hydrogen storage capabilities, the dependence on expensive rare-metal catalysts (*e.g.,* platinum), and the development of appropriate infrastructure all represent formidable uncertainties in the timely delivery of a commercial product. By depending solely on a technology without a known delivery date, action on transport-sector emissions can be significantly delayed:

> "…by skewing research toward costly large-scale demonstrations of technology well before it's ready for market, governments risk

repeating a pattern that has sunk previous technologies such as synfuels in the 1980s. By focusing research on technologies that aren't likely to have a measurable impact until the second half of the century, the current hydrogen push fails to address the growing threat from greenhouse gas emissions from fossil fuels" (Science, 2004).

12.1.4.3 Fuel availability and price volatility

Not all fuels are widely available, particularly in developing countries. Many alternative fuels may simply not be available at the time that the BRT system is going into operation, and thus fuel availability will constrain the selection of propulsion technology.

Diesel and electricity are by far the most widely available fuels. Low-sulphur diesel is available in a growing number of countries, but its availability is still fairly limited in developing countries. Current price levels in different countries are well documented through the GTZ International Fuel Prices publication (Metschies *et al.,* 2007). As evidenced in Figure 12.35, subsidy and tax levels can make a significant difference in actual fuel costs.

Natural gas as a bus fuel requires a supply network in close proximity to fleet maintenance and parking areas. Some cities in developing countries have natural gas and others do not. Some cities have the gas but have not yet invested in the specialised equipment such as the pipeline, compressors, dehumidifiers, and other equipment necessary to make the fuel usable as a bus fuel. When Delhi was forced to switch to natural gas, the lack of sufficient sources of supply led to severe disruption of bus services. These problems can be mitigated with proper planning.

Hydrogen fuel cells are currently not commercially viable in developing countries without massive subsidies, but an additional problem is the availability of hydrogen. Hydrogen is not found in any substantial quantities in the natural environment. For this reason, hydrogen is not really a fuel type but rather an energy carrier, in a similar manner that an electric battery is an energy carrier. Most of the hydrogen fuel cell projects developed to date have relied upon electrolysis, which generates the hydrogen from passing an electrical current through water. This requires special equipment and electricity. The other likely source of hydrogen is natural gas, which then requires a natural gas supply. Both approaches require expensive specialised equipment. Further, depending on how the electricity is generated to produce the hydrogen, the life cycle emissions from a fuel cell vehicle can actually be considerably higher than a standard diesel vehicle.

The electricity for electric trolleybuses is less of a problem than the cost and maintenance of the electric conduit and the electricity stations that feed them. Electric-diesel hybrids which do not require electric conduits mitigate the need for expensive conduits.

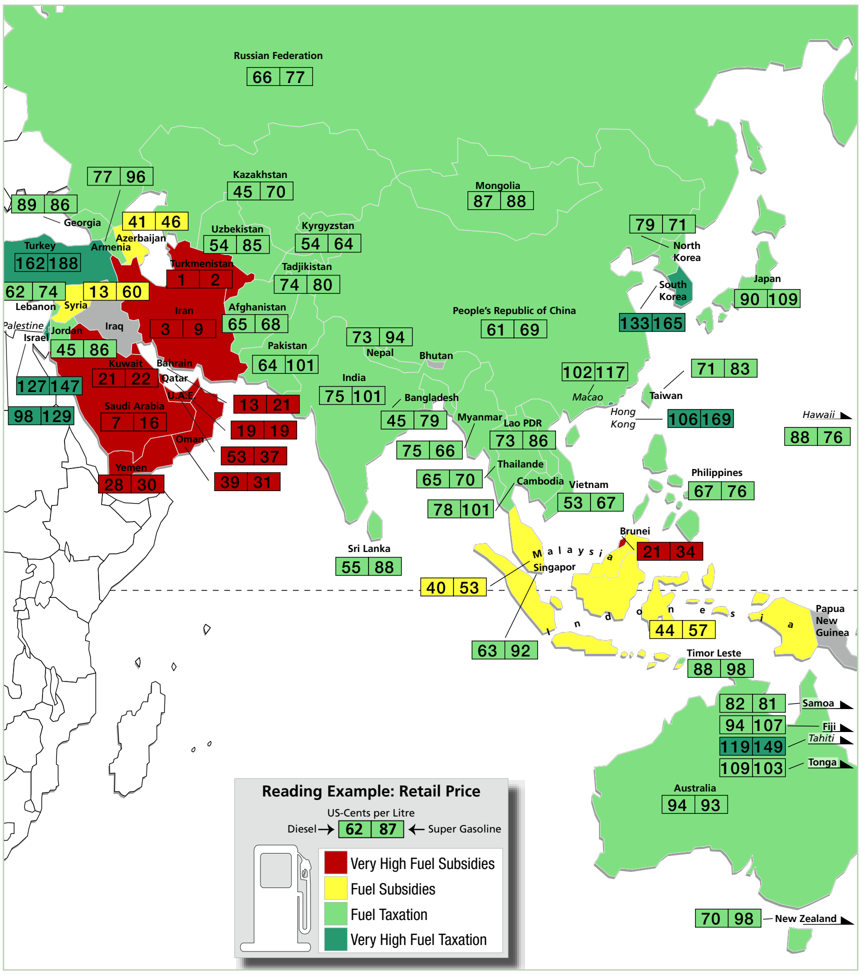
In every case, a vulnerability and risk analysis associated with fuel supply systems is necessary, as public services like transportation cannot risk interruptions in operation due to problems within gas pipes tubes or power outages.

The risk of future fuel price volatility is a related issue. System operators will want to insulate themselves against the risk of sudden future

Fig. 12.35

The yellow and red coloured areas represent countries with significant fuel subsidies.

Image courtesy of GTZ SUTP



increases in fuel prices. A vehicle technology should be selected which reduces the risk of future fuel price increases.

Fig. 12.36
Sudden changes in fuel costs can put the entire economic viability of a system into jeopardy.
Photo by Lloyd Wright

While predicting future fuel supplies is difficult, this risk can be mitigated by having the vehicle operator negotiate long-term fixed rate contracts with the relevant fuel suppliers, or by buying futures options in the fuel. The risk can also be mitigated by the use of vehicle technologies that can run on multiple fuel types.

If a city has a nearby natural gas supply, it may be worth the investment in the necessary infrastructure and equipment to provide natural gas at the depot if a reasonably-priced long-term supply contract can be negotiated with the gas supplier. A local supply of natural gas is important because it is relatively easy to pipe but expensive to ship. Similarly, if oil is produced in the country, particularly if it is produced by a state run oil company, it may be possible to negotiate a long-term fixed rate supply contract.

Conversely, if a country has hydroelectric power, or large supplies of coal, or declining electricity demand (as in the case of the former socialist countries of Central and Eastern Europe and the former Soviet Union) it may be that future electricity supplies are more predictable than prices for diesel or natural gas. Again, the issue may be more whether or not a long-term supply contract can be negotiated. It is not enough to assume that a government company will mean stable future fuel prices. System operators should still protect themselves with long-term supply contracts or futures contracts. Long-term supply contracts also may be possible from commercial providers though they will cost more.

In the case of Quito, for example, the decision to go with electric trolley buses was initially related to low electricity costs. While the initially low electricity rates made the operational costs competitive with diesel-based systems, a subsequent deregulation of the Ecuadorian electricity sector has seen electricity costs increase. Based on this experience, the future expansion of the trolley system in Quito may be limited.

12.1.4.4 Reliability

Reliability of the propulsion technology is a major concern for a BRT system. Vehicle breakdowns in a BRT system are more serious than in a normal bus operation because a broken down bus will congest the BRT lane and lead to a significant disruption of service.

One of the main advantages of diesel fuel is that the vehicle technology is more mature, and with proper maintenance vehicle breakdowns are more predictable and easier to repair (Figure 12.37).

Fig. 12.37
Diesel technology has a long operational track record, and thus the technology's robustness and maintenance requirements are well know.
Photo by Lloyd Wright

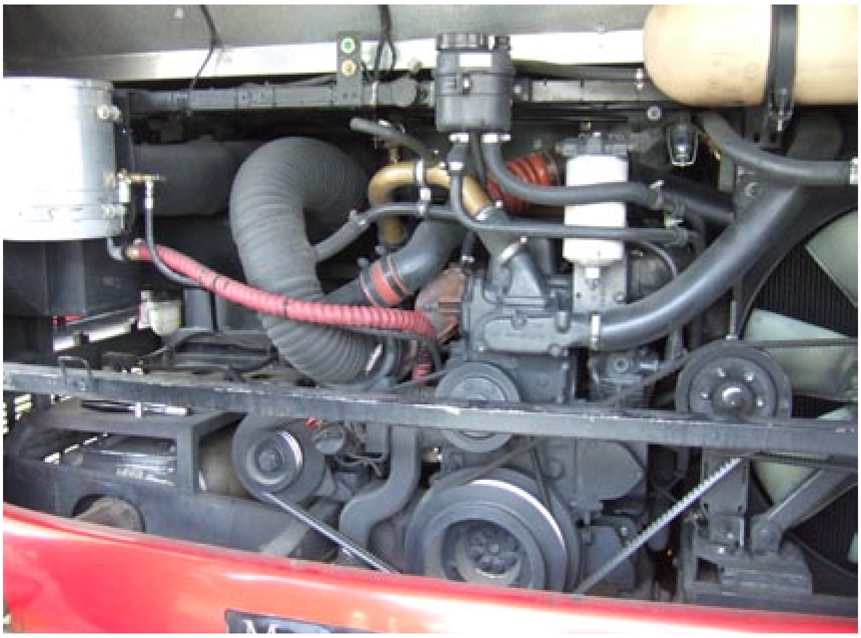


Fig. 12.38
Many of the operating companies in Bogotá directly contract the vehicle manufacturers to provide maintenance services for the vehicles.
Photo by Lloyd Wright

Electric trolleybuses themselves have excellent maintenance records, but there can be problems with power failures and maintenance failures in the electric conduits. Electric trolleybus technology is still used in BRT systems São Paulo but it is being phased out not because of electricity prices but because of failures in the overhead conduit due to poor maintenance. This problem is partially controllable by turning over control of conduit maintenance to the bus operator who has a bigger stake in a breakdown than the power company.

In any case, most important is a maintenance contract with the supplier. In the case of TransMilenio manufacturers have staff at the depot for major repairs (Figure 12.38). It is therefore critical that the degree of technical support offered by the vehicle supplier be a major consideration in the procurement contract. In Quito, for example, Spanish electric trolley bus suppliers were selected over lower-cost Russian suppliers largely because of the quality of maintenance support offered.

If the risks of vehicle breakdown are extremely high, local maintenance capacity low, and the ability of the local operators to mobilise capital weak, it may be worth exploring the option of leasing the vehicles from the manufacturer. This option is being considered for the Dar es Salaam BRT system.

For any vehicle, it is also advisable to run fuel and general performance tests locally that simulate the anticipated conditions of operation before reaching a decision. Vehicles that work great in developed countries in temperate climates may work poorly in tropical climates on poor roads with major drainage problems.

12.1.4.5 Noise

Acceptable noise levels should also be specified within the bus procurement specifications. Excessively loud vehicles are both a health hazard as well as a detriment to the marketing image of the public transport service.

Noise levels are determined by several variables including:

- Fuel and propulsion system technology;
- Design of propulsion system;
- Size of vehicle relative to engine size;
- Dampening technologies and exhaust system employed;
- Quality of road surface; and
- Maintenance practices.

Some fuel and propulsion systems, such as electric vehicles, are naturally quiet. In other instances, the design of the propulsion system can encourage smooth operation as well as the dampening of sounds. Ensuring incentives for well-maintained vehicles and roads will also help achieve lower noise levels. In Bogotá, the vehicle specifications mandate that internal noise levels of the vehicles are specified to not exceed 90 decibels (dB).

A very quiet vehicle does introduce other issues. Electric trolley technology operates with little noise. However, in turn, the lack of noise can create a hazard for pedestrians who may not be aware of the presence of an on-coming vehicle. This type of hazard is particularly a concern for the sight-impaired who are often quite dependent on noise to guide their movements.

12.1.4.6 Ventilation and temperature standards

The presence or absence of climate control inside the vehicles can have an enormous impact not only on the quality of service but also on the costs of operations. In some climate conditions, air conditioning is not that critical to customer comfort, but in other cases, the lack air conditioning alone may be enough to induce middle and upper income passengers to stay in cars. Requiring air conditioning is critical to a high status image for the system, but it will also put upward pressure on the fare. As a general rule, climate control inside the vehicles is preferred if it is at all possible given the profitability of the system.

Whether air conditioning is used or not, attention should be given to the amount of air turnover inside the vehicle. In highly crowded vehicles, the air quality can quickly deteriorate without adequate ventilation.

12.1.5 Other physical characteristics

Besides the vehicle length and propulsion system type, there are a range of other characteristics that will define the vehicle. The specifications set forth during the operational design will determine many other additional factors regarding the technical specification required for the bus, including the following:

- Body type (segregated from chassis, unified);
- Number of doorways and size of doorways;
- Type of system for opening and closing the doorways;
- Doorway location;
- Transmission type (automatic, manual, retardor);
- Type of propulsion system
- Engine location (front, centre, rear);
- Engine power rating;
- Acceleration capacity;
- Braking technology;
- Braking capacity;
- Suspension type (springs, hydraulic);
- Road turning radius (internal and external);
- Axle load capacity.

If decisions on these parameters are made without reference to the operational design, serious design mistakes can occur. For example, in Jakarta, a vehicle with plenty of capacity was procured but the vehicle had only one door. This single door decision causes such a serious deterioration in passenger boarding and alighting speed that the entire capacity of the corridor was severely compromised. Similarly, vehicles with axle loads above the weight bearing capacity of the road surface treatment on the corridor led to rapid deterioration of the road bed.

In most countries there are regulations and conditions that public transportation vehicles must meet pertaining to bus import, assembly, and manufacturing. Identifying all conditions and restrictions thus becomes necessary, along with any required certification and standardization processes. Norms, standards and regulations that cover the following fields are present in most countries:

- Environmental performance;
- Security standards;
- Physical conditions;
- Country of origin;
- Local manufacturing ratios;
- Import procedures and requirements;
- Tariffs and other import duties;
- Handicap accessibility.

In the absence of laws and regulations governing these issues, setting the vehicle technical specification should take these issues into consideration in any case, following international norms.

As a reference, Table 12.7 is a summary of the vehicle specifications put forward by the public company overseeing the Bogotá TransMilenio system. The actual specifications for any given city will vary depending on local preferences and circumstances.

Table 12.7: Bogotá vehicle specifications (trunk-line vehicles)

Vehicle attribute	Spec ification
Load weights	
GAWR front axle load	7,500 kg
GAWR middle axle load	12,500 kg
GAWR rear axle load	12,500 kg
GVWR total weight	30,000 kg

Vehicle attribute	Spec ification
Load weights	
GAWR front axle load	7,500 kg
GAWR middle axle load	12,500 kg
GAWR rear axle load	12,500 kg
GVWR total weight	30,000 kg
External dimensions	
Maximum width	2.60 metres
Maximum height	4.10 metres
Overall minimum length	17.50 metres
Overall maximum length	18.50 metres
Maximum front overhang	3,000 mm
Maximum rear overhang	3,500 mm
Load weights	
GAWR front axle load	7,500 kg
GAWR middle axle load	12,500 kg
GAWR rear axle load	12,500 kg
GVWR total weight	30,000 kg
External dimensions	
Maximum width	2.60 metres
Maximum height	4.10 metres
Overall minimum length	17.50 metres
Overall maximum length	18.50 metres
Maximum front overhang	3,000 mm
Maximum rear overhang	3,500 mm
Floor height from ground	
Minimum height	870 mm
Maximum height	930 mm
Turning radius	
Minimum between sidewalks	7,400 mm
Maximum between sidewalks	12,100 mm
Minimum between walls	7,400 mm
Maximum between walls	13,400 mm
Chassis and body	
Body type	Integral body or self-supporting body
Modification	Every modification of the chassis must be formally approved by the manufacturer
Certification of static load proof	Can by obtained by physical proof or computational model Minimum certified roof resistance in 5 minutes: 50% of GMV Maximum deformation in every point: 70 mm

Vehicle attribute	Spec ification
Passenger space	
Total passenger capacity	160 passengers
Seating capacity	48 passengers
Colour of seats	Red
Number of preferential seats	6
Colour of preferential seats	Blue
Standing passenger area	16 m^2
Standing design capacity	7 passengers per square metre
Wheelchair capacity	1 space for wheelchair (90 cm x 140 cm); Located in the first body of the bus in front of the second door
Layout of seats	2-2, 2-1, 1-1, 1-0; Perimeter or front-to-front
Internal dimensions	
Free internal height	2,100 mm minimum
Superior visibility height	1,850 mm minimum
Inferior visibility height	600 mm minimum; 850 mm maximum
Corridor width	600 mm minimum
Seating characteristics	
Characteristics	Individual seats Closed in back Direct anchorage to the vehicle floor Without upholstery or cushioned Without sharp edges or rivets
Materials	Plastic Washable Self-extinguishing and flame retardant No release of toxic gases during combustion
Seat dimensions	
Distance between seats	700 mm
Distance between seats front to front	1,300 mm
Seat depth	350 mm minimum; 430 mm maximum
Seat height (measured from floor)	350 mm minimum; 450 mm maximum
Back height	500 mm minimum; 600 mm maximum
Seat width	400 mm
Handles and handrails	
Characteristics	Surfaces without sharp edges End finished in a curve Continuous Non-slip surface
Dimensions	Diameter: Between 30 and 45 mm Horizontal handrail height: 1,750 mm minimum and 1,800 mm maximum Distance between vertical balusters: 1,500 mm or very two seats

Vehicle attribute	Spec ification
Windows	
Front window type	Laminated
Type, all other windows	Tempered
Colour of window	Green
Transparency level	70%
Advertising	Windows without advertisement
Inferior module	Fixed to the body with adhesive
Superior module height	Minimum: 30% of total height of the window Maximum: 50% of total height of the window
Doorways	
Number of passenger doorways	4
Position	Left side of bus
Minimum free width	1100 mm
Free height	1900 mm
Door opening time	2 seconds
Emergency doors	Type: single door Number of emergency doorways: 2 Minimum free width: 650 mm Free height: 1,800 mm With stairs covered and with a pneumatic opening system
Control and instrumentation	
Logic unit	Communication display in view of driver GPS and communications antennas Tachnograph (with register and storage of instant velocity, distance travelled, times of operation and non-operation over 24-hour period)
Control centre communications	Voice communication equipment
Instrumentation	Odometer with pulse output connected to the logic unit Complete instrumentation with alarms for low pressure of the air brake system and motor oil system
Ventilation	
Air renewal requirement	Minimum 20 times per hour
Noise	
Maximum internal sound level	90 dB(A)
Destination signs	
Number and size of signs	1 in front: 1950 mm x 300 mm 2 on left side: 450 mm x 250 mm
Visibility	Visible from a distance of 100 metres
Technical standards	
Bus	NTC 4901-1 Mass Transport Passenger Vehicles
Test methods	NTC 4901-2 Mass Transport Passenger Vehicles
Local standards	ICONTEC (Colombian Technical and Standardisation Institute)

Source: TransMilenio SA

12.1.6 Vehicle aesthetics

The aesthetic nature of the vehicle technology should also be an explicit component of the design and specification process. Vehicle styling, colour and aesthetic features figure greatly in the public's perception of the system. Some manufacturers are now emulating many of the design features from light rail systems (Figure 12.39). Simply by covering the wheels and rounding the bus body, these manufacturers have greatly increased the aesthetic appeal of their product. These initial vehicle designs are relatively expensive, in part because other features such as optical guidance systems often accompany them. However, the idea of creating a customer pleasing form is not necessarily a costly endeavour.

It is important that the external and internal aesthetic design includes modern elements which differentiate the system from informal public transportation. Design elements that typically illicit a positive customer reaction include:

- Aerodynamic curvature of body, especially a rounded front;
- Covered wheels (Figure 12.40);
- Panoramic windows;
- Window colour and tint;
- Paint colour combination;
- Interior lighting of vehicle;
- High-quality floor and interior materials;
- Interior layout and design (Figure 12.41);
- Information systems for passengers (electronic information boards and sound systems).

12.1.7 Strategic considerations

There are a series of considerations that have to be taken into account besides technical, environmental or legal factors. These considerations are important from a political point of view and a strategic point of view and although they are not directly related to the system's performance they are directly associated with its impact and positive contribution to the local transportation service and to users.

12.1.7.1 Government policies

Fuel type selection can also be affected by political considerations which may influence the systems stability, permanency, and economic viability. In particular, development policies

Fig. 12.39
Despite giving a distinctly light rail appearance, the Civis vehicle is actually a bus.
Photo courtesy of US TCRP media library

Fig. 12.40 and 12.41
Covered wheels and well-designed interiors are seemingly small details that can have a big impact on the public's perception of the vehicle.
Left photo courtesy of NBRTI
Right photo courtesy of Advanced Public Transport Systems (APTS)

established by administrations must be considered, including factors such as:

- Tariff structure for transportation equipment depending on their respective technology (it might be possible to obtain preferential tariffs for low emission fuels);
- Policies regarding subsidies;
- Tax incentives for clean vehicles;
- Future plans and investments in clean fuel production initiatives;
- Future fuel supply infrastructure expansion and maintenance plans.

12.1.7.2 Local assembly and production

Renovating bus fleet technology and public transportation creates provides a great opportunity for developing new industries and implementing technologies that can be groundbreaking in the country in question.

It is desirable that when selecting vehicle technology, one can take into account the real possibility of incorporating local businesses into whatever part of the process is possible. For instance, it may be possible to encourage local fabrication, chassis assembly, body fabrication and mounting (Figure 12.42).

Choosing more modern and state of the art technology might make it more difficult to try and obtain parts and equipment locally, as this equipment might not be available might no be offered. Further, such technology may prove difficult for local manufacturers to deliver. However, this should not mean that the technology chosen for the project has to be obsolete. On the contrary, even if the chosen technologies are advanced an effort should be made to could foment and encourage local industries to develop local capacity. Not being able to incorporate local business into the process might generate an unfavourable public opinion towards the project in some sectors and could also generate political opposition.

12.1.7.3 Ensuring competition among vehicle suppliers

The vehicle specifications should be developed in part to ensure that the widest number of manufacturers will be able to compete in the market. By maximising the number of eligible manufacturers, the operating companies will be able to undertake a competing tendering process that will minimise the vehicle costs. Limiting

Fig. 12.42
Cities such as Bogotá have put in the right incentives to encourage major vehicle manufacturers to set-up local manufacturing facilities.
Photo by Lloyd Wright

the vehicle type to just one or two manufacturers will quite likely increase the purchase costs.

12.1.8 Docking systems

The process of aligning the vehicle to the station will affect the speed of passenger boarding and alighting, customer safety, and vehicle quality. Vehicle alignment to the station can be critical for both the lateral and longitudinal distances. The lateral distance between the vehicle and the station is important in terms of customers easily and safely crossing. The longitudinal placement of the vehicle can be critical if the station has precise doorways that must match up with the doorways on the vehicle. If the station has an open platform without doorways, then the longitudinal placement is less critical.

Docking precision is also required to avoid damage to the vehicle. If a driver comes to close to the station platform, a collision between the vehicle and the station can easily occur. Rubber padding on the platform sides can mitigate some of the damage, but ultimately, small collisions will damage the vehicle.

Section 8.3.3 of this Planning Guide has already touched upon the issue of vehicle to platform guidance systems. To an extent, the need for exact vehicle to platform alignment is avoided through the use of a boarding bridge. In this case, a flip-down ramp is extended from the vehicle to the platform. The driver only needs to align the vehicle to within 45 cm of the platform to make a boarding bridge function properly.

Optical, mechanical, and magnetic docking systems are all possible technologies to assist the driver in the docking process. Of course, as the technology becomes increasingly sophisticated, the vehicle and station costs can rise dramatically.

Mechanical guidance systems for station alignment are similar to the mechanical systems used on busways in Adelaide (Australia), Essen (Germany), and Nagoya (Japan). Such systems can also be used only at station to bus interfaces.

Optical systems can either be manually or electronically activated. A manual optical system is simply a visual target for the driver to focus upon while nearing the station platform. The driver's focus on the visual target can be improved through the use of a magnified video screen fed by a small camera under the vehicle or integrated into the wheel. Electronically-operated optical systems function in a similar manner but rely upon a micro-processor to actually steer the vehicle. Thus, as the vehicle nears the station, the micro-processor assumes control of the vehicle from the driver. This type of system is utilised on BRT systems in Las Vegas and Rouen (Figures 12.43 and 12.44).

Finally, the Phileaus vehicle of Advanced Public Transport Systems (APTS) offers a magnetically controlled guidance system. Magnetic materials are inserted into precise locations of the roadway. A micro-processor interface with an on-board magnetic sensor then steers the vehicle along a precise path. Like the Civis, the Phileaus bus can be operated without driver intervention at both stations and along the busway.

For the developing city application, a simple optical system that is manually operated by the driver is quite sufficient. In conjunction with boarding bridges, these systems offer a cost-

Fig. 12.43 and 12.44
The dotted white line along the lanes of the Rouen system permit an optical guidance system to manoeuvre the vehicles to a high degree of accuracy.
Left photo courtesy of NBRTI
Right photo by François Rambaud

effective way of achieving a sufficiently precise docking position in order to permit rapid boarding and alighting.

12.1.9 Fleet size

The fleet size will be determined entirely by the operational system. A method for calculating the fleet size needed based on projected passenger demand was outlined in Chapter 8 (*System capacity and speed*). The calculation formula is repeated here for convenience:

Operational fleet size for corridor (Fo) = **Demand on critical link (D) (pphpd)** X **Travel time for a complete cycle (Tc) (hours)** / **Vehicle capacity (Cb) (passengers/vehicle)**

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

The total fleet size will affect the likely purchase cost of the vehicles. As the economies-of-scale increase, manufacturers will provide operators with a better offer. In some cases, the pooling of a purchase order can help minimise purchase costs.

12.1.10 Vehicle costs

The one variable that often has an over-riding impact on vehicle selection is cost. The amortisation of the vehicle is one of the principal operating costs that affects both operator profitability as well as the fare level. An exorbitantly high vehicle will reduce system profits and make fares unaffordable. For this reason, attention to vehicle costing must be undertaken jointly with the operational costing model.

Some of the principal determinants of a vehicle's cost are vehicle size (*i.e.,* length) and the type of propulsion system. Other factors, such as interior design, engine size, type of chassis, and number of doorways, will also play a role. For example, a low-floor vehicle will cost approximately 25 percent more than a higher-floor model.

Economies-of-scale in production is a major factor that affects pricing. For this reason, two 12-metre vehicles often cost less than a single 18-metre vehicle. This result occurs to the significantly greater number of 12-metre vehicles produced in the world.

Because vehicle cost is not fixed but a function of the scale of production, some cleaner new technologies face initial high costs which create a barrier to entry. However, cleaner vehicles also yield social benefits beyond just public transport passengers. These factors may in some cases constitute a justification for short term subsidisation of cleaner bus technologies.

Standard diesel vehicles are by far the least expensive bus technology. Most BRT systems are now using Euro II or Euro III diesel technology. Clean diesel technology in combination with good-quality fuel can often meet or even exceed the emission standards of supposedly more sophisticated propulsion systems.

After diesel, CNG is perhaps the next most common type of fuel used in road-based public transport today. In India, a CNG compatible standard bus increases the vehicle cost from about US$30,000 to about US$40,000 (Figure 12.45). Elsewhere, a CNG vehicle will increase the procurement price by between US$25,000 and US$50,000. The cost difference varies widely depending on how powerful the engine needs to be, which will be a function of vehicle size.

The electric trolleybus is also a fairly common propulsion type. Electric-trolleys can be three times the cost of a comparable Euro II diesel vehicle. Further, the added infrastructure costs of the electric conduit and transformers can be significant. These extra costs are somewhat

Fig. 12.45
In India, fairly cost-effective CNG vehicles are currently be supplied in substantial volumes.
Photo by Lloyd Wright

Fig. 12.46
The cost of the electric-trolley vehicles in Quito along with the cost of the associated infrastructure resulted in a comparatively expensive system.
Photo by Lloyd Wright

mitigated by the longer life of electric-trolley vehicles. Due to the lower mechanical demands on the electric-trolley technology, the life of the vehicles can be twice that of diesel vehicles. Usually electric trolley buses also have a backup diesel motor in case of a power failure, which accounts for part of the difference in cost.

Quito utilised electric-trolley technology on its first BRT corridor in 1996 (Figure 12.46). The technology was chosen primarily for its environmental benefits. Quito's historical core is a World Heritage Site and the municipality wished to reduce the impacts of diesel emissions on the integrity of the built environment. Further, Ecuador's electricity generation is primarily from hydro-electric sources. The price of each vehicle was approximately US$700,000. In total, the added infrastructure for the electric-trolley corridor pushed capital costs to over US$5 million per kilometre. By comparison, a subsequent BRT corridor in Quito using Euro II diesel technology resulted in capital costs of approximately US$585,000 per kilometre.

Electric-diesel and electric-CNG hybrids are likely to be the next generation of clean vehicle technology. Currently electric-CNG and electric-diesel hybrids are available at US$75,000–US$100,000 more than a standard diesel bus. To date, no BRT system has utilised these technologies.

The BRT business plan outlined in Chapters 15 and 16 will determine how much money can reasonably be spent on the vehicle procurement without compromising the financial viability of the entire BRT system. The business plan will indicate the maximum cost of the vehicle procurement (depreciation) and the maximum ongoing operating cost (including maintenance) that can be sustained, and how much the system will have to charge per vehicle-kilometre in order to cover these costs. The technical specification can require high levels of environmental protection, high noise standards, high aesthetic standards, and high levels of passenger comfort, but only within the parameters that the business plan has determined to be financially viable. In some cases, the system being designed will be highly profitable, as in the case of TransMilenio, giving the system designers considerable freedom to set a high technical standard. In other cases, such as in very poor countries, passenger demand may be highly sensitive to even modest increases in fare prices, placing tight constraints on the options for the technical specification.

Many local conditions will influence the cost of the vehicle. Vehicles technologies with a longer history and large manufacturing volumes will hold a cost advantage in terms of manufacturing economies of scale. Many traditional Indian

Fig. 12.47
Specialised manufacturing of low-volume vehicles can dramatically increase overall costs.
Image courtesy of the TCRP BRT image library

buses, for example, are mass produced using a truck body, and are some of the lowest cost buses in the world, but they leave much to be desired from the point of view of customer comfort. New vehicles technologies will generally have lower manufacturing volumes and may incur additional research and tooling costs (Figure 12.47).

The location of the manufactured vehicle will also be a factor. Production sites in developing countries will often hold an advantage in terms of labour and site costs. Further, locally manufactured vehicles will have lower shipping costs to arrive at the destination city. However, in some instances, locally manufactured vehicles may raise quality issues in comparison to developed-nation production sites.

In some cases, the vehicle manufacturers themselves have determined that certain branches of their own company are responsible for specific regions, even though they may not be the lowest cost producers. For example, the cost of good quality name brand buses in Africa is sometimes more expensive only because the manufacturers have determined that the African market is to be supplied by the European branch rather than the Latin American or Asian branch of the company. The following factors are likely to strongly influence local vehicles procurement costs:

- Chassis cost;
- Body Cost;
- Sales tax;
- Licensing and paperwork fees and costs;
- Circulation permit costs;;
- Operational insurance costs
- Financing cost;
- Projected vehicle life;
- Projected resale value;
- Projected repair requirements.

For imported vehicles, there will be the following additional cost considerations:

- CIF costs;
- Shipping costs;
- Shipping insurance costs;
- Local port storage fees;
- Tariffs;
- Value added tax;
- Local customizing costs;
- Domestic transportation costs from ports to cities.

Table 12.8 provides a summary of vehicle cost estimation based on technology types and location of manufacture. However, these costs could be significantly underestimated particularly in the case of Africa which has limited proximate vehicle manufacturing capability, high financing costs, and high duties and value added taxes.

Determining an aggregate cost might be difficult considering there are several determining factors involved. However, it is advisable for BRT project managers to communicate with local vehicle manufacturers throughout the process, as this will allow for a comparison of all price options pertinent to vehicle choice.

In practical terms, a joint work effort will be required between system operational design and

Table 12.8: Bus vehicle costs

Vehicle type	Purchase cost (US$)
Small, new or second-hand bus seating 20-40 passengers, often with truck chassis	$10,000–$40,000
Diesel technology, produced by indigenous companies or low-cost import (12-metre)	$40,000–$75,000
Diesel bus meeting Euro II standard, produced for (or in) developing countries by international bus companies (12-metre)	$80,000–$130,000
Standard OECD Euro II diesel bus sold in Europe or United States (18-metre articulated)	$200,000–$350,000
Diesel with advanced emissions controls meeting Euro III or better	$5,000 to $10,000 more than a comparable standard diesel bus
CNG, LPG buses	$25,000 to $50,000 more than a comparable standard diesel bus (less in developing countries)
Hybrid-electric buses	$75,000 to $150,000 more than a comparable standard diesel bus
Fuel-cell buses	$850,000 to $1,200,000 more than a comparable standard diesel bus

Source: Adapted from IEA, 2002b, p. 120

the business plan. An iterative process will help to find an optimal vehicle technology solution that both meets a high-level of customer comfort as well as achieves cost-effectiveness.

12.2 Fare systems

"Buy the ticket, take the ride."

—Hunter S. Thompson, journalist and author, 1937–2005

12.2.1 Decision factors in choosing a fare system

The first step in selecting an appropriate fare collection and verification technology is deciding what sort of operational plan, what sort of fare policy, and what sort of institutional structure is needed for the specific BRT system.

The method of fare collection and fare verification has a significant impact on the operational efficiency of the BRT system, the ability of the system to integrate routes with each other and with other public transport systems, and the fiscal transparency of the system. Before making a final decision on a fare collection system technology, critical decisions regarding the operation of the fare collection system and the fare policy need to have already been made. Decisions that should already have been made include:

- Operational plan for the fare collection system;
- Fare policy and fare structure;
- Institutional structure of the fare collection system.

12.2.1.1 Operational plan for the fare collection system

As was discussed in Chapter 8 (*System capacity and speed*), an efficient fare collection system technology can significantly reduce boarding and alighting time, but also times queuing to purchase tickets and clearing turnstiles.

The process and physical location of the fare collection and fare verification activities can be determinant in the functioning of the overall system. "Fare collection" is the process of customer payment for the trip. "Fare verification" is the process of checking whether a person has actually paid for their intended (or completed) journey. In many BRT systems, fare collection and fare verification occur relatively simultaneously. However, it is also possible to collect fares in one manner and verify fares in another. For example, in many European public transport systems, fare collection is frequently conducted off-board while fare verification is conducted on-board.

Off-board payment system

The decision to collect and verify fares on or off-board will have a significant impact on the potential passenger capacity of the system. Off-board fare collection and fare verification reduces the long delays that generally accompany on-board payment, particularly if the driver is also responsible for fare collection and fare verification.

Pre-board fare collection and fare verification also carries another benefit. By removing the handling of cash by drivers, incidents of on-board robbery are reduced. Further, by having an open and transparent fare collection system, there is less opportunity for circumstances in which individuals withhold funds.

On many systems, the amount of time it takes the driver to process the fare collection can be a substantial contributor to delay in the buses operations. These impacts are quantified in Chapter 8. Because the level of delay increases with the number of passengers boarding and alighting at any given stop, the importance of off-board fare collection systems is not uniform across a BRT system. It is very important at high volume stations, and may be of marginal importance at other stops.

While off-board fare collection and fare verification can considerably improve system efficiency by reducing dwell times, it does require the construction of closed station environments. There must be a physical separation between those customers who have paid and those who have not. The closed stations bring with them issues of cost, road space, aesthetics, and potentially severance. The average station cost in the TransMilenio system was approximately US$500,000 each (Figure 12.48). Of course, it is also possible to construct simpler closed stations for less; the stations on the Ecovía line in Quito cost in the area of US$35,000 each.

Closed stations, though, also bring other benefits besides increased system efficiency. Such stations provide more protection from inclement weather, such as rain, wind, cold, and strong sun. Also, closed stations hold advantages in terms of providing security from crime as well as discouraging loitering.

On-board fare verification

Systems in Europe often employ "proof of payment" techniques, also known as "honour" systems. In such systems, very little actual fare verification is conducted. Occasional checks by public transport staff are done to control fare evasion. The actual payment of the fare is largely reliant on the public's goodwill and overall willingness to comply. For those caught without a valid fare during the random inspection process, a penalty is applied. Honour systems do entail pre-board fare collection, usually through a vending machine or kiosk (Figure 12.49). From the fare payment point onwards, the customers proceed directly to the public transport vehicle without inspection.

One of the main advantages of proof of payment fare systems is that it allows one to avoid the construction of a closed entry station. No physical

Fig. 12.48
Off-board fare collection and fare verification increases system efficiency by reducing station dwell times. However, it does require construction of stations that form a closed environment between paid (inside the station) and unpaid (outside the station) customers.
Photo by Carlos F. Pardo

Fig. 12.49
A pre-board fare vending machine in Berlin.
Photo by Lloyd Wright

separation between the station and the outside area is necessary. There is no separation of those who have paid from those who have not paid. This design advantage can help reduce station construction costs as well as permit better station design in areas with limited physical space.

The main disadvantage of such a system is that they usually result in some revenue loss. In principal, such systems do not have to have negative consequences for total system revenue if enforcement is sufficiently rigorous and fine levels are set high enough to create a significant deterrent for non-compliance. However, rigorous enforcement of fare evasion is something of an unpleasant business. Enforcement authorities have to be quasi police, either armed or physically large. Sometimes people are unable to figure out how to pay the fare, either because the cash point was not working, or closed, or it failed to punch the fare card properly. People need to retain the fare card, and sometimes it gets lost. When one of these things happens, it is highly unsettling for the passenger, for they face a stiff penalty, and a humiliating encounter with enforcement agents.

Such systems have not been widely used in developing countries. They tend to be prevalent in subsidised public systems where there is less direct institutional concern about collecting the fare revenue. This kind of system also requires a legal framework that allows verification staff (that usually are not police staff) to have de-facto police powers in the collection of penalties from violators, and a procedure for collecting when the passenger does not have the money to pay the fine. This legal framework is absent in many developing countries. Fare verification by personnel walking through the buses also is difficult on very crowded systems. Even with stringent verification requirements, cities such as Quito face non-negligible amounts of fare evasion. As such, the viability of operating an effective honour system in a low-income city is yet to be proven.

In any case, the operational plan needs to decide if fare collection will be only off-board, only on-board, or both on board and off board.

Fare integration

Most BRT systems offer free transfers within the BRT system, both between trunk lines and between trunk and feeder lines. Some BRT systems may also offer free or discounted transfers between vehicles inside the BRT system and other modes of transport like metros, commuter rail lines, and standard buses. "Fare integration" means that the passenger pays no premium for moving from one mode to another and can do so without any physical difficulty. "Fare compatibility" is a lower form of integration in which the customer may pay twice but simply can use the same fare technology (*e.g.,* smart card) between the two systems.

If the system designers have built physically enclosed stations where passengers can transfer between lines without having to again pass through a turnstile, then cash and token-based ticketing systems can still be used. If the system requires such transfers to be made in an open environment, then more costly fare technologies (such as magnetic strip or smart card technology) will be required.

12.2.1.2 Fare policy and fare structure

It is critical that the fare policy and the fare structure for the BRT system be selected before the fare technology is selected. The options for the fare policy are discussed at length in Chapter 16 (*Operational costs and fares*). In general, there are five types of fare structures:

1. Free fare;
2. Flat fare;
3. Zonal fare;
4. Distance-based fare;
5. Time-based fare.

As the name suggests, a "free fare" structure requires no fare payment whatsoever. In this case, public transport is truly "public" with no requirement for payment by the user. Instead, the system's costs are typically covered by another funding stream, such as parking fees for cars. Systems or routes in cities such as Hasselt (Belgium), Denver (US), Miami (US), and Orlando (US) utilise a free fare structure. This type of fare structure is obviously the simplest to implement as well as creates considerable cost savings in terms of not requiring fare equipment or enforcement.

A "flat fare" structure means that a single tariff will allow a customer to travel anywhere within the system. Whether the trip is for 500 metres of 20 kilometres, the price is the same. Many Latin American cities, such as Bogotá and Quito, make use of a flat fare structure. In these cities, a flat fare structure brings with it social equity advantages. Since the poorest families tend to live at the periphery of the city, a sort of cross-subsidy is introduced where wealthier, centrally located customers are effectively supporting a lower fare for those that live some distance from the CBD.

A "zonal fare" structure is essentially a simplified distance-based structure. For each "zone" that the trip crosses, there is an additional cost to the customer. If a customer travels within just a single zone, there is a flat fare for the entire zone. The advent of magnetic strip and smart card technology has made zonal fares somewhat unnecessary since these technologies can handle more precise distance calculations. However, the zonal system does have the advantage of being relatively easily understood by customers.

"Distance-based fare" structures charge a tariff in relation to the number of kilometres travelled. Customers travelling a farther distance will pay more than someone travelling just a short distance. A distance-based structure most closely matches the actual costs being incurred to the system. At the same time, distance-based tariffs require an order of magnitude more technological sophistication in order to successfully implement and manage.

A "time-based fare" structure allows a customer to travel for a given amount of time for a flat fare. A higher fare is charged for going beyond a certain time limit. Like distance-based fares, a time-based structure requires a higher degree of technical sophistication. Both time-based and distance-based structures are more costly to develop and implement.

A system may actually utilise a combination of different fare structures. For example, the feeder services may utilise a free fare or flat fare system while the trunk services could be a zonal fare or distance-based system. In fairly sophisticated fare systems, such as that utilised in Seoul, time- and distance-based fare elements are combined into a single package.

12.2.1.3 Institutional structure of the fare system

Institutional arrangements for the fare collection and verification system vary widely from system to system, with different benefits and risks. Most systems have the following components:

- The manager of the money (usually a bank or money manager);
- The equipment provider;
- The fare provider;
- The fare system operator;
- The public transport authority or its parent agency.

How these functions are related institutionally depends upon the technical competence of the public transport authority or its parent agency, the level of concern about corruption, the type of system desired, and the need for financing it with private money.

It is fairly standard for the manager of the money, the equipment provider, and the fare provider

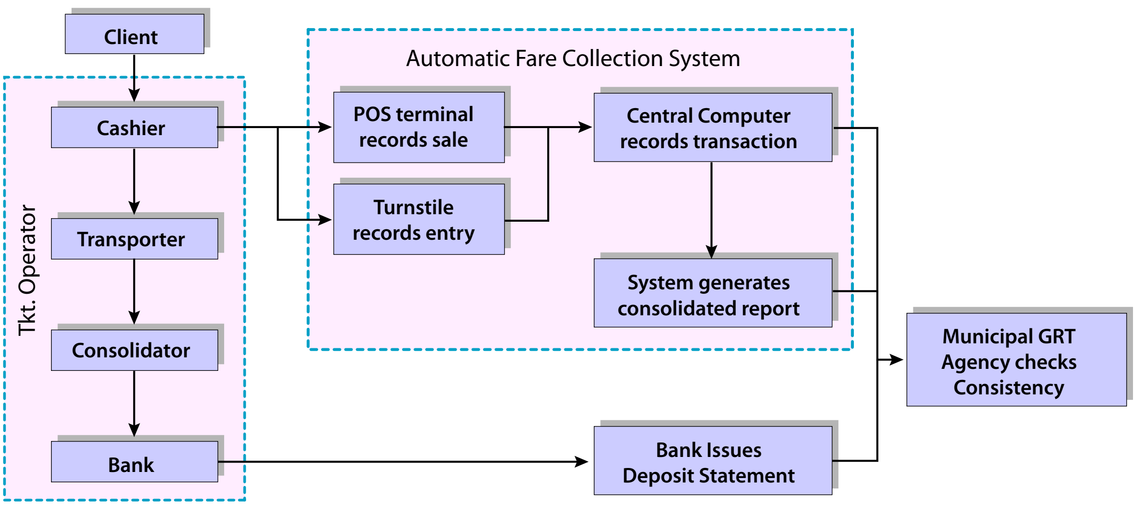


Fig. 12.50
Institutional relationships in a typical fare system.
Graphic courtesy of Fabio Gordillo

to be closely associated, while the fare system operator is separate. This allows the equipment provider/financial manager to monitor the fare system operator in order to avoid corruption. Figure 12.50 outlines a typical system structure.

In the case of TransJakarta, splitting the responsibility for operating the fare system and procuring the fare system equipment led to major problems. When problems with the equipment technology emerged, the fare system operator was unable to fix them, and claimed to have no legal responsibility for fixing the problem. The fare system equipment supplier should have been liable but the contract signed with TransJakarta did not provide for this eventuality. There was nothing inherently wrong with the structure, but any structure not backed by solid legal contracts outlining financial liability for service failures can lead to disaster.

In the case of TransMilenio in Bogotá, the fare system was implemented through a unique Build-Operate Transfer (BOT) model. In this case, there was a competitive tender for a single company to both procure the fare system equipment and operate the fare system. The company that won this tender, Angelcom SA, both selected and paid for the fare equipment and operates the system (Figure 12.51). The contract signed was between the public operating company (*i.e.,* TransMilenio SA) and the private firm, not between the Department of Transport or the Department of Public Works and the private firm. The private concessioned company in turn receives a fixed percentage of the revenues from TransMilenio. A third company was contracted by TransMilenio to be responsible for managing the revenue once collected. All fare revenue in TransMilenio is placed by the operator into a Trust Fund, and this company manages the TransMilenio Trust Fund on behalf of all the parties with a vested interest in the fair and accurate division of this revenue: TransMilenio SA, the trunk line operators, the feeder bus operators, and the fare collection company.

This Build-Operate-Transfer institutional model for the fare system had some advantages and disadvantages. The system was eventually able to attract private investment for the fare system equipment in a country where private investment was difficult to secure due to political risk. This private financing reduced the initial capital cost of the TransMilenio BRT system. However, the fare system operator receives 10 percent of TransMilenio's total revenue, whereas their operating costs are probably much lower. As such, it puts an unnecessary financial burden onto system operations. It would have been less costly if the fare system were simply purchased outright by TransMilenio.

Fig. 12.51
In Bogotá, the contract for purchasing and operating the fare collection equipment was awarded to a single private firm.
Photo by Lloyd Wright

This structure did assure that the fare system functioned on a basic level. Because the concessioned company's profits are determined based on the success of the system, they have a vested interest in making sure the system operates properly. Because they were also responsible for operating the system, they had a vested interest in getting equipment that functioned properly. Because they were a fare system operating company, they also knew more about the appropriate technology than the government, and were able to negotiate better equipment contracts with subcontractors and receive lower prices. By privatising the procurement contract, they also removed the risk of corruption in the procurement process.

On the other hand, the concessioned company bought relatively cheap equipment in an attempt to save money. They complied with their contractual obligations but the quality standards were reasonably poor, the design was inflexible and of poor quality, implementation was slow, and there were a host of technical problems in the first month of operation. These problems could have been solved within the current structure by having harsher penalties for poor performance, and by having TransMilenio specify in the tender a higher technical standard for the fare equipment. TransMilenio could even have handled the procurement independently and then "novated[1)]" the contract to the winning fare system operator. In this way, the operating system bidder becomes the owner of the new equipment, and can be required to pay for the investment, but the government would retain tighter control over the equipment selection process.

It is fairly common in the public transport industry to separate initial equipment procurement from operations. This practice is usually done when there is a public transport authority that directly collects the farebox revenue, and where there is no expectation that the operating company will provide the investment into the system. Technology providers such as Ascom Monetel, ERG, INDRA or Scheidt and Bachmann, have focused their attention on the technology development and integration tasks, leaving the fare system operation to the public transport agencies. This structure can reduce the ongoing financial burden that a BOT would impose. However, if equipment procurement and operations are separated, contracts will have to be structured carefully to ensure that the equipment providers are responsible to the operating company for system maintenance.

12.2.2 Choosing a technology

Once the critical decisions about the operational system, the fare policy and structure, and the administrative structure are determined, an appropriate fare collection system technology can be chosen.

Since the first BRT systems were opened back in the 1970s, fare system technology has evolved rapidly and prices are falling. Today there is a great diversity of technology options for ticketing systems. This section outlines some of the technological options for collecting and verifying fares.

1) "Novated" is a legal term meaning the replacement of one obligation by another by mutual consent of both parties.

12.2.2.1 Technological elements of a fare system

Normally, the physical equipment of the fare system consists of the following:

1. Payment medium
   The payment medium is usually cash, tokens, paper tickets, magnetic strip cards, or smart cards.
2. Point-of-Sales (POS) terminals
   These terminals are cash points where a ticket, token, magnetic card, or smart card can be purchased, or value can be added onto an existing card.
3. Value-deduction terminals
   These terminals are usually turnstiles and/or card readers.
4. Central computer
   The central computer is the repository of the various information streams; the central computer is typically connected to the Point-of-Sales terminals and the value-deduction terminals via a telecommunications and/or GPRS link.

12.2.2.2 Single or multiple payment medium

A system may employ a single fare medium or use two different ones for the different types of fare being offered. For example, many systems offer one type of payment medium for single trips and another type of payment medium for multiple trips.

The reason for this differentiation has to do with the cost of the payment medium itself. Issuing a smart card can be a somewhat costly investment for the public transport system. The efficiency gains of a smart card can make it a worthwhile investment when used by a loyal customer over weeks and months of trips. By contrast, making that same investment for a one-time user of the system may not be cost-effective. If a one-time user of the system was to somehow keep the smart card after his or her trip, then the public transport company would have lost revenue on the trip.

Thus, public transport systems, such as Delhi and Bangkok metro systems and the Quito BRT system, utilise two different payment mediums (Figures 12.52 and 12.53).

However, there is also much advantage in having a common payment medium for all

Fig. 12.52 and 12.53
The Delhi Metro utilises both smart card technology and electronic token technology. The smart cards allow multiple trips while the token is for single trips.
Photos by Lloyd Wright

journeys. The multiple payment mediums can be confusing to customers and act as a barrier to entry for many. Handling multiple fare mediums can also result in process and administrative inefficiencies.

12.2.2.3 Payment mediums

The following payment mediums are in common use in BRT systems around the world:

- Coins;
- Tokens;
- Paper tickets;
- Magnetic strip cards;
- Smart cards.

No one solution is inherently correct. The choice of fare collection system often involves a trade-offs between costs, simplicity, cultural conditions and service features.

Coin / token systems

Coin and token systems are amongst the simplest technologies available to handle fare collection and fare verification. These systems can be quite robust and economical to operate. New York City's mass transit system worked on a token based system for over one hundred years.

The number of sales personnel and can be reduced and ticketing machines are not necessary with coin-based systems because the customer does not need to go through the cumbersome process of programming the electronic card. Instead, the currency acts directly as the fare payment and verification mechanism. There is no need to issue any paper tickets to customers. Also, there is typically no queue at the exit side of the trip either. Thus, while other systems may involve at least three separate customer queues (purchase fare, verify fare at entrance, and verify fare at exit), coin-based systems require the customer to only enter one queue (verify fare at entrance). However, once a ticket is purchased, contactless cards tend to have higher throughput at the turnstile; coin-based systems will likely move only 8 to 12 passengers per minute versus 15 to 20 passengers per minute with contactless cards.

In Quito, Ecuador, a simple coin-based system has worked successfully for both the city's "Trolé" line and "Ecovía" line (Figure 12.54). The system thus avoids the need to purchase any payment medium whatsoever. In Quito, an attendant window does exist, but it is only to give change to those who require it. Upon exiting a system, passengers simply file through one-way exit doors without the need for further

Fig. 12.54
This fare verification machine in Quito handles both coins and a magnetic strip fare card.
Photo by Lloyd Wright

fare verification. Quito's system also allows the flexibility to utilise discount fare cards as well; these fare cards are based on magnetic strip technology. However, the entire turnstile device can fit into a limited space, and thus permits two turnstiles within a relatively narrow station.

Naturally, coin-based systems depend upon the availability of coins in the local currency. Further, the coins must be available in a combination that matches the desired fare level. If coins are not part of the local currency, then tokens are an option. However, the inclusion of tokens in the fare collection system defeats many of the benefits of coins. While still providing a relatively simple fare system, tokens require all customers to purchase from a machine or sales point. This activity increases the amount of customer queuing required to use the system. Another alternative is to utilise fare collection turnstiles that handle paper currency. However, this technology is not nearly as robust as coin readers. The extra moments required for authenticating the currency note will slow down the entry process and thus reduce system capacity. This problem is exacerbated by the poor quality of older currency notes often found in developing nations.

However, with this simplicity there are some limitations. Coin-based systems are only usable with flat-fare structures, and cannot offer multi-trip discounts, time of day discounts, or free transfers to other modes without physical integration facilities. Of course, there are many conditions where a flat fare is desirable, as discussed in Chapter 16 (*Operating costs and fares*). Also, by combining a coin-based system with another technology (such as magnetic strip cards or smart cards), then multiple-trip fares are also possible.

Coin and token systems are subject to the illegal use of slugs and counterfeit coins. The handling and administrative requirements related to coin collection and transaction accounting are also more labour intensive.

Fig. 12.55
A simple paper ticket as utilised on the Rome metro.

Paper systems

Simple paper tickets are issued for bus and rail systems throughout the world (Figure 12.55). In such instances, ticket purchases typically take place at vending booths, machines, kiosks, and other shops. The ticket will often have enough recognisable detail to prevent counterfeiting.

In some instances, paper ticket systems will require a validation step to the process. The validation will involve inserting the paper ticket into a stamping machine. This machine will mark the time and sometimes the location of the validation. The validation process becomes important when paper systems are distance-based and/or have time limits on usage.

Verification of paper tickets can also take place manually upon entrance into the system or may only be verified on the occasion of a random inspection. In some instances, the verification may be done by the bus driver or a conductor. Such manual verification is quite problematic in high volume systems. The queuing points are likely to be quite lengthy and the detrimental impact on customer travel times would be significant.

Normally, verification for paper ticket systems is conducted on an honour system. However, the viability of an honour system in most developing cities has yet to be substantiated.

Paper systems can permit distance-based fares, but verification of distance travelled can only be verified manually. The feasibility of verifying distances travelled within in a high-volume system is somewhat suspect.

Magnetic strip technology

Magnetic strip technology has had a relatively long history of application and success in the field. Magnetic strip technology has been used successfully in metro systems around the world (Figures 12.56 and 12.57). There are two different standards for magnetic strip cards:
1.) The standard-sized ISO 7810 card;
2.) The smaller Edmonson card.

The technology requires the pre-purchase of the magnetic card for system entry and verification. Capital costs can be significant for both the fare vending machines and the magnetic strip readers at the fare gate. The systems require fare vending personnel and/or card vending machines (Figure 12.58). The advantage of magnetic strip technology is the relatively low-cost of the fare cards themselves, US$0.02–US$0.05 per card. However, unlike smart cards, magnetic strip cards have a limited lifetime. The cards are made of coated paper and can be relatively easily damaged. However, systems such as the Bangkok Skytrain are reporting several years of usage per card.

The cards may be programmed to allow multiple trips and can also permit different fares to be charged for different distances travelled. Some system providers utilising magnetic strip cards also elect to permit discounted fares for individuals purchasing multiple trips.

The cards typically are verified both at entry into the system and at the exit. Data from the verification turnstile can provide system operators with information on customer movements.

Smart cards

Smart card technology is the latest advent in the fare collection field. Smart cards contain an electronic chip that can read and process a variety of information regarding cash inputs, travel and system usage with the highest possible security level. Smart cards also permit a wide range of information to be collected on customer movements, which ultimately can assist in system development and revenue distribution. BRT systems in Bogotá, Goiânia, and Guayaquil have successfully employed smart card technologies (Figure 12.59). Smart cards permit the widest range of fare collection options such as distance-based fares, discounted fares, and multiple trip fares. Such cards also bring a complete set of system statistics that can be helpful to system managers.

Fig. 12.56 and 12.57
There are two types of magnetic strip cards: 1. The standard sized card, as shown in this example from the New York subway (left image); and, 2. The smaller Edmonson card, as shown in this example from the Paris Metro (right image).

The main drawbacks of smart card technology are the relative cost of the card and complexity. The systems require fare vending personnel and/or card vending machines. The system also typically requires verification machines at the system exits, if distance-based fares are utilised. In each instance, the risk of long customer queues, especially during peak periods is increased at the point of sale but reduced at the turnstile. In addition to the costs of the vending and verification machines, each smart card is a relatively costly expense. Current prices are in the range of US$1.00–US$3.00 per card. The card cost depends on the card complexity.

Virtually all smart cards conform to the ISO 7816 size standard. The card material can vary with such options as PVC, PET, and even paper. The activation mechanism can either be realised by way of "contact" cards or "contactless cards". As the name implies, contact cards

Fig. 12.58
Magnetic strip vending machine in Bangkok.
Photo by Lloyd Wright

Fig. 12.59
The smart card utilised on the Bogotá TransMilenio system.

Fig. 12.60
The Mexico City smart card.
Photo courtesy of Volvo

require insertion in the card reader slot in order to establish an electrical contact between the reader and the card in order to be verified. Contactless cards permit the user to pass in the vicinity of the turnstile reader to activate verification (Figure 12.60). For this reason, contactless cards offer greater customer ease and convenience. Traditionally they have been more expensive than cards using a magnetic strip, but costs are coming down.

There are various types or standards of smart cards available in the market. Nevertheless there are some basic standards that define the features of the cards. Different manufacturers have developed their proprietary protocols and operating systems that define the security and compatibility between cards and reading devices (Mifare, Sony, Infineon, etc.). The basics characteristics that define most smart cards are:

- Mechanical (external dimensions, materials, longevity);
- Electrical source;
- Communications protocol;
- Commands interoperability.

The most common standard is defined in the "ISO 14443 A or B Standard", which details the card characteristics.

The microchip on the card can either be "memory only" or "memory with micro-processing" capabilities. Cards with a memory chip can only store data, and have pre-defined dedicated processing capabilities. The addition of micro-processing allows the smart card to actually execute applications as well. For example, a micro-processor chip can allow the stored value of the smart card to be used for purchases outside the public transport system. .

In Hong Kong, the Octopus card permits users to make purchases at shops as well as pay for public transport (Figure 12.61). The Octopus card allows up to HK$1,000 (US$125) of stored value to be placed on the card. While this feature can be quite convenient, smart cards with micro-processing capabilities tend to be more expensive than other types of cards. However, for systems such as Hong Kong, the flexibility and utility of the cards make them a worthwhile investment. There are currently an estimated 14 million Octopus cards in circulation in Hong Kong. Approximately 9.4 million transactions take place in Hong Kong each day using the Octopus card.

Once a card brand such as the Octopus is established, its ability to penetrate into a wide variety of related markets is significant. Octopus started with a core network of transport services in 1997 and soon expanded into almost all forms of transport payment services (Figure 12.62).

Likewise, the Octopus card is finding utility in several applications outside the transport sector. Some of these outside payment applications include supermarkets, convenience stores, fast food franchises, vending machines, photocopiers, cinemas, and sports venues (Figure 12.63). As of September 2006, 24 percent of Octopus

Fig. 12.61
Hong Kong's "Octopus" card allows customers to use the card for purchases in shops outside of the public transport system.

transactions took place in the retail sector (Chambers, 2006). The flexibility of such cards means that the system's marketplace and potential for profit can extend well beyond the transport sector. Such market diversity can help to strengthen overall company performance.

The Seoul T-Money system is in many ways quite similar in performance to the Octopus card. T-Money can be used both on the city's metro system as well as other transport services such as the BRT system. Likewise, T-Money is crossing over into many non-transport applications, such as retail purchases. The fare card systems in Hong Kong and Seoul are also showing much creativity in the form of

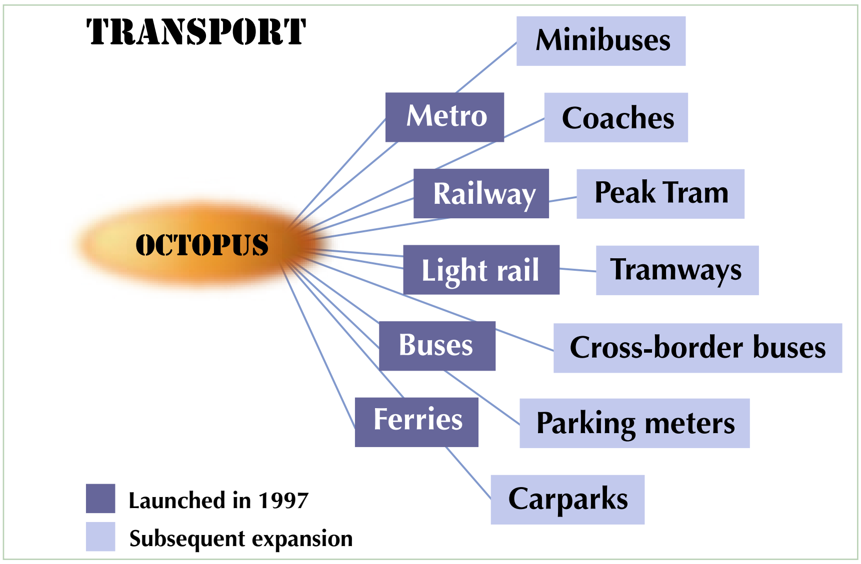


Fig. 12.62

Hong Kong's Octopus card has expanded from a core network of public transport services into a broader array of services including parking meters and carparks.

Graphic courtesy of Octopus Holdings Limited

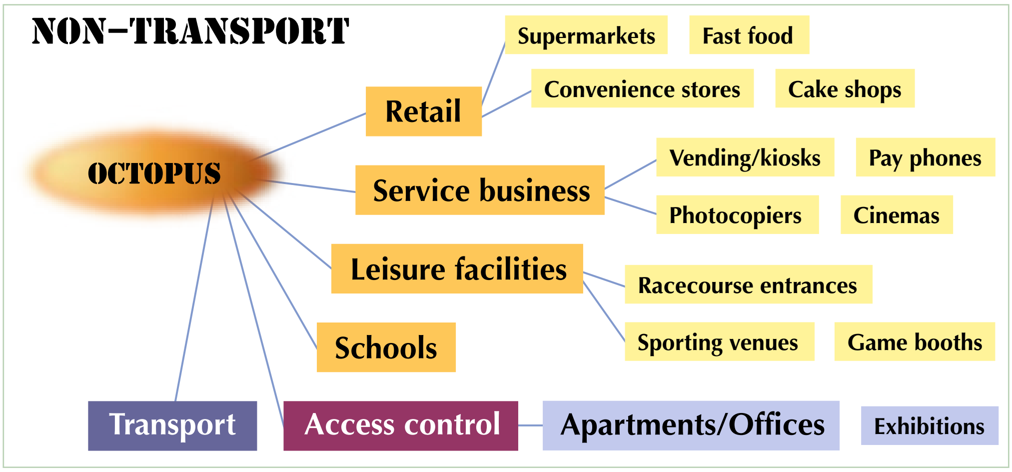


Fig. 12.63

The reach of the Octopus card extends well beyond the transport sector.

Graphic courtesy of Octopus Holdings Limitd

the cards themselves. Both cities are allowing customers accessorise themselves with fare chips that are inserted in a range of products such as watches and key chains (Figure 12.64). Also, in the future it will be likely that customers will be able to swipe their mobile telephones in order to make a payment.

There are several kinds of cards at the market, and prices vary depending on card capacity and the standard used. Typically smart cards for transport applications have from 1k to 4 k of memory. A 4k card will be able to support multiples applications like e-money transactions.

Unlike magnetic strip cards, though, smart cards have a long life and can be re-used for periods in the range of 5 to 10 years. As smart

Fig. 12.64

The smart card chip can actually be placed in a range of products besides fare cards. In Seoul, customers can pay for their travel by swiping their watch or key chain across the card reader.

Photos courtesy of the City of Seoul

cards become more common, the cost of the cards will undoubtedly continue to fall.

From the operational point of view, smart cards, have the widest range of capabilities for developing multiple applications and to solve very complex functionality needs, this include the possibility of managing multiple fares (time, distance based, flat fares, among others) and also the possibility of using the smart card for virtual integration without the necessity of integration stations.

Perhaps one of the most valuable characteristic of smart cards is the throughput performance, which is the highest available on the market.

From the financial point of view, although smart cards have a relative high initial cost, (US$1.00–3.00 per card) the cost per transaction is significant less than that of magnetic stripe tickets. Some systems designers estimate that maintenance costs for contactless smart cards equipment are between 7 to 10 percent of the initial investment, compared with 15 to 20 percent for magnetic stripe systems.

Besides the cost of the cards, the chief disadvantage of smart cards is the relative complexity of the implementation. Jakarta went over one-year before the smart card system could actually function. Implementing a smart card system is an order of magnitude more difficult than many other payment mediums. Smart card systems are not yet in the category of a "plug-and-play" technology, as much software programming and specialised skills must accompany the implementation.

Summary of payment mediums

This section has provided an overview of each of the major payment mediums. Table 12.9 summarises the major decision factors for each technology.

12.2.2.4 Turnstile options

Beyond the payment medium, there are also a range of technological options related to fare reading equipment and turnstiles. As with other equipment, the different product options offer trade-offs regarding cost and performance.

Turnstiles are generally available in two different sizes: 1.) Full-body height; and 2.) Half-body height. Most public transport systems utilise half-body height turnstiles, although in some cases, full-body height devices are applied in situations where there is little oversight. For example, Quito employs a half-body height turnstile at the entrances which also include the presence of a fare agent. However, a full-body height turnstile is used at the exits since there is less surveillance of the exits by station staff.

In general, there are three turnstile types: 1.) Wing barrier turnstile; 2.) Rotating-arm turnstile; and 2.) Gate-arm turnstile. Many high-quality metro rail systems make use of a wing barrier turnstile. Systems such as the London

Table 12.9: Summary of fare collection technologies

Factors	Coin system	Paper system	Magnetic strip system	Smart card system
Set-up / equipment costs	Medium	Low-Medium	High	High
Operating costs	Low-Medium	Low	Medium	Medium
Level of complexity	Medium	Low	High	Medium
Number of customer queues per trip	1	2-4	2-4	2-4
Can provide customer tracking information	No	No	Yes	Yes
Allows automated fare verification	Yes	No	Yes	Yes
Allows distance-based fare schemes	No	With difficulty	Yes	Yes
Passenger capacity through turnstile	Medium	Low to high*	Medium	High
Supports high-tech image of system	Medium	Low	Medium-High	High
Space requirements for fare equipment	Medium	Low	High	High
Susceptibility to counterfeiting	Medium	High	Low to medium	Low

* Paper ticketing can support high customer flows if an "honour" system is utilised for the fare verification.

Underground, Washington Metro, Delhi Metro, and the Bangkok Skytrain make use of this technology. Once the card reader deducts the payment, the “wings” of the turnstile automatically open to allow the customer to enter. The wing barriers provide a professional appearance and are effective against fare evasion. Some of these devices will detect whether the customer has passed, in order to ensure the device does not strike the person when closing. In other cases, such as in Bangkok, the wing is set to a timer; if the customer does not clear in time, the turnstile will strike them.

A rotating-arm turnstile also offers good protection against fare evasion. In this case, once the reader recognises the fare payment, the rotating-arm is released from its fixed position (Figure 12.65). The arm will then be free to rotate a single turn in order to ensure only one person can pass through. Systems such as the Bogotá TransMilenio system make use of a rotating-arm turnstile. Unlike the wing barrier and the gate-arm turnstile, the rotating arm turnstile is not friendly to those in wheelchairs or customers with baby strollers. If a system only utilises rotating-arm turnstiles, then persons with wheelchairs or strollers may effectively be locked out of the system.

The gate-arm turnstile is a simpler, less costly device that swings open like a gate (Figure 12.66). When payment is made, the turnstile is released. However, if the gate is held open, many persons could conceivably make their way through the opening. The gate-arm turnstile does not lock again until it returns to a closed position. The advantage, though, of the gate-arm turnstile is its user friendliness towards wheelchairs and strollers. Likewise, persons pulling luggage can easily enter as well. Further, unlike the wing barrier, there is no threat of the device closing upon a person halfway through the entry. Quito utilises the gate-arm turnstile for all entries into its Trolé and Ecovía lines.

A system may actually make use of several different turnstile types. For example, in many TransMilenio stations, a single gate-arm turnstile is offered to patrons requiring greater ease

Fig. 12.65
Rotating-arm turnstiles, as utilised in Bogotá.
Photo by Lloyd Wright

Fig. 12.66
The gate-arm turnstile as used in Quito can be quite user-friendly, but does tend to increase the risk of fare evasion.
Photo by Lloyd Wright

Fig. 12.67
A drop-arm turnstile option is provided for customers with special needs in many TransMilenio stations.
Photo by Carlos F. Pardo

of entry, such as those in wheelchairs or a parent with a stroller (Figure 12.67). In rail systems there is generally ample space at entries to permit multiple technologies. By contrast, BRT systems operating in a narrow roadway median may have less space to offer multiple turnstile options. For example, in Quito, the narrow station widths imply that only two turnstiles can be fitted. Thus, when only a narrow space is provided, it is less likely that multiple technologies will be an option.

12.2.3 Bogotá and Jakarta case studies

Fare collection and fare validation are critical for quality of service and financial stability of the BRT system. Nevertheless, less effort is often assigned for its preparation, procurement and supervision than the effort given for trunk vehicle operations. Both Bogotá and Jakarta had troubles in the fare collection system at the beginning of their operation, which were gradually solved throughout the first years of operation.

In both cities there were initial operational difficulties with the fare collection systems, such as long queues for card acquisition, low throughput of the turnstiles and loss of trips stored in the cards. There were also problems with the quality and integrity of the data (sales, validation). These problems resulted in some loss of confidence amongst customers in the system. These problems could have been avoided if better planning, procurement design and supervision were applied.

Fig. 12.68
Jakarta's smart card system could not be utilised through the first periods of operation due to several technical and managerial problems.
Photo by Lloyd Wright

Bogotá and Jakarta wanted their systems to have up-to-date electronic fare collection systems using contact-less cards. In both cases they allocated relatively little time for system design, testing and implementation. Both systems also had contractors without previous experience in public transport operations.

The main differences between Bogotá and Jakarta were the institutional set-up and the contracting procedures. Bogotá procured and supervised the concessioned firm through a single organisation, the public company known as TransMilenio SA.

By contrast, Jakarta split equipment and operation between two different agencies. The equipment was procured the Transportation Department (Dinas Perhubungan or DisHub). The system supervision and operation was managed by the newly created operational entity known as TransJakarta. There was an apparent lack of coordination between these agencies. Furthermore, equipment and software procurement was separated from day-to-day operations, contracted afterwards directly by TransJakarta.

In terms of contracting procedures, TransMilenio SA conducted an open bidding process, while the Transportation Department in Jakarta apparently selected the provider directly. Later in the process TransJakarta selected the operator among a short list using an accelerated contracting process. Both companies operating the systems in Bogotá and Jakarta were visionary, entrepreneurial, but lacked the capacity to timely comply with the contract requirements. They were able to sort out the difficulties, but solutions only came after many months of problems (Figure 12.68).

Initial operations in both cases were not smooth. Bogotá initiated with paper tickets that were replaced in the first four months of operations by contact-less smart cards. Despite the requirement in the contract of using Edmonson ticket for 1 or 2 passenger trips, and contact-less cards for multiple trips only (3 or more), the local contractor asked for contact-less cards only, which was accepted by TransMilenio SA under the operators' own risk. Cards were not charged to the users, and hence the required card stock was, and still is, very large. Initial operation of the validation (check-in and check-out) was not reliable, and users lost confidence on multiple fares, which in turn increased queues at fare booths.

Problems with Bogotá's validation process resulted in an important change in the operational scheme: exit validation was eliminated due to numerous complaints by the users. Additionally, part of the stock of cards was unreliable and needed to be retired. Finally, a group of turnstiles using local integration were below the required standards and were replaced by more reliable equipment at the operator's expense.

In the case of Jakarta, most of the problems were the result of implementing a fare collection system without careful adaptation to the local conditions by a contractor without enough expertise to comply with the system requirements. Reliability of the power supply also caused problems, as did wireless communication scheme. There were even disputes on the property of the software rights. TransJakarta was reluctant to receive the system procured by the Department of Transport, and the contracted fare collection operator was also concerned.

Both cities found ways to improve the operations and quality of service of the fare collection component through their contractors. Current operations do not exhibit the problems reported in the first year. Nevertheless their experience shows lessons on some recommended practices:

- There are not "off-the-shelve" systems ready for "plug-and-play". Time is required for system adaptation to local conditions and requirements (*e.g.,* reduced fares for certain populations such as students, zone and time based rather than flat faer, level of integration with the feeders). It is unlikely that a system could be adapted, developed, deployed and tested in less than 6 months. Hence, fare collection often becomes the critical path in system implementation.
- Open and competitive bidding is preferred to direct contracting, even if it takes more time and introduces relatively high transaction costs. In an open bidding process competition forces prices down (for the benefit of the users) while keeping the quality and service standards at a high level.
- It is advised that selection criteria include financial capability and experience in the implementation and operation of fare collection systems. Bogotá tried with the concept of technical assistants to comply with this experience, but this figure did not worked well. Technical assistants did not share the risks of the main contractor and were not involved in the level it was expected for the project benefit. It is important that experience is checked and those members of the contractor (in case of consortiums) have an important share in responsibility of contract compliance (*e.g.,* more than 20 percent).
- Integration of installation and operation is recommended, as the operator is part of the decisions on system design and equipment and software acquisition. If contracts are separated is likely that the operator may claim that problems are the result of design and installation, not its own ability to perform according to standards set forth.
- Performance based contracts are preferred over standard procurement contracts. The concept behind this is that the BRT System is acquiring is a service; rather than the hardware and software of the fare collection system, what is important is the throughput and reliability of the solution provided. Which solution is finally provided is a decision of the operator.
- Testing each component and their integration is needed, hopefully well in advance to system commissioning.
- Supervision of fare collection is as important, if not more, than bus operations. This should be taken into account when organising the agency in charge of planning, developing and supervising BRT system operations.
- Having one agency running the entire system is better than trying to coordinate efforts by several agencies.
- Provide for contracting arrangements that promote system growth (additional sales). It is advised that remuneration for the fare collection provision and operation grows with passenger ridership. Current formulas in Bogotá contracts do not promote increased sales, at least from the perspective of the operator.
- Charging the reusable fare cards (*e.g.,* contact-less cards), for example through a

returnable deposit, can be better than providing them for free. Users may take responsibility of the cards and this reduces damages and required stock. However, charging for cards adds considerable administrative complexity and it can discourage use of the system.

12.3 Intelligent Transportation Systems (ITS)

"We live in a society exquisitely dependent on science and technology, in which hardly anyone knows anything about science and technology."

—Carl Sagan, scientist and writer, 1934–1996

12.3.1 Control Centres

As noted in Chapter 11 (*Infrastructure*), a centralised control centre will help ensure smooth and efficient BRT operations. While not all systems utilise an automated control centre, it is increasingly becoming a standard practice in higher-quality systems.

A cornerstone of a modern control system is automated vehicle location (AVL) technology which allows the tracking of the vehicles along the corridor. With AVL the control centre can direct vehicle movements so as to avoid vehicle bunching, react swiftly to problems and emergencies, and allocate capacity resources in swift reply to changes in demand.

Chapter 11 (*Infrastructure*) has already discussed some of the logistical and organisational issues around the development of a control centre. This section provides a brief review of the technological options.

While the benefits seem clear, the costs of a real-time control system would seem prohibitive for a developing city. However, the cost of central control technologies has steadily decreased during the past few years. Thus, even cities in developing nations may now wish to consider the advantages of a central control system.

Several options exist to link buses and stations with a central control office. In some instances, a simple radio or mobile telephone system may suffice. However, increasingly Geographical Positioning Satellite (GPS) technology is providing an effective communications link (Figure 12.69). GPS technology permits real-time information on vehicle location and status. Modern GPS systems can track vehicle movements with an accuracy of 2 to 20 metres, depending on the type of system and local conditions. GPS location technology combined with a wireless communication system (GPRS) is utilised within the control system of Bogotá's TransMilenio system. By using the GPS technology in conjunction with vehicle managing and tracking software and a voice communications system, Bogotá is able to closely control vehicle headways (Figure 12.70). A control

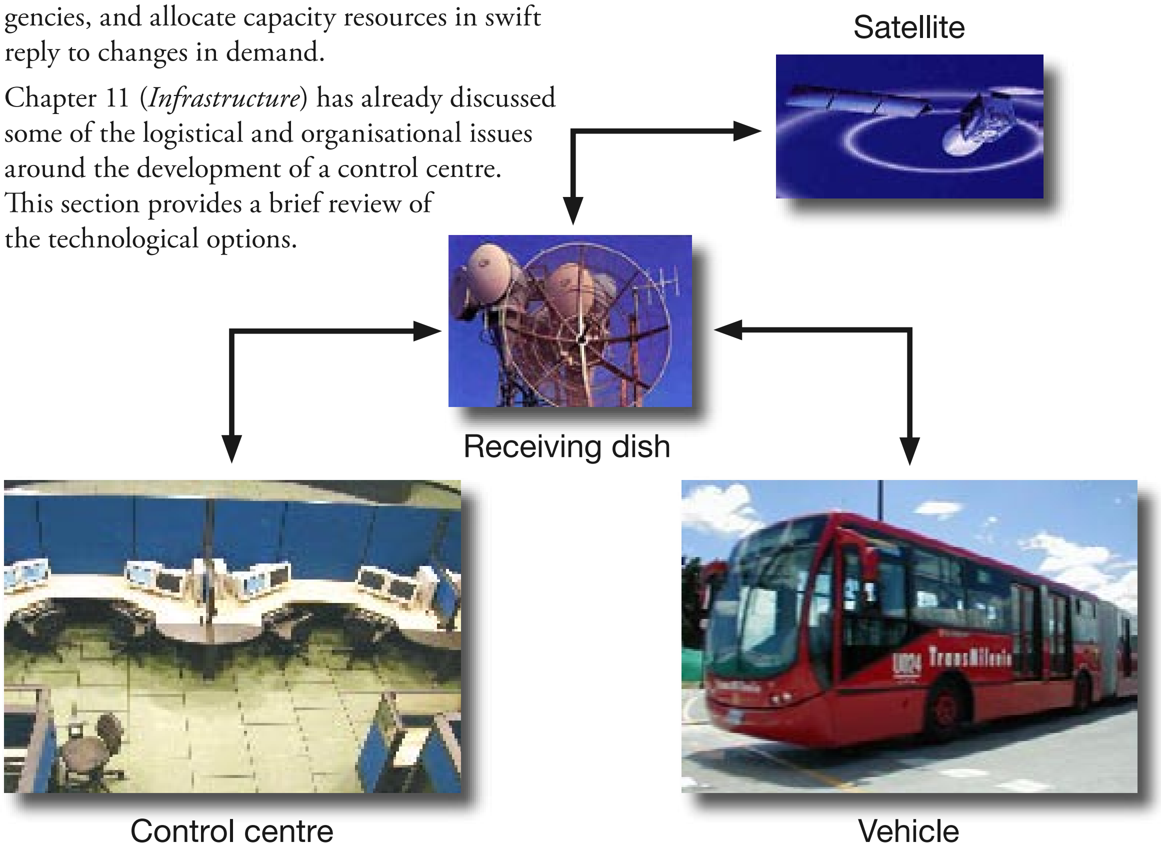


Fig. 12.69
GPS technology can be cost-effectively utilised for vehicle tracking capabilities.
Images courtesy of TransMilenio SA

centre operator will direct a driver to slow down or speed up depending on the location of other vehicles and the demand requested. Further, if a surge in demand occurs at a particular station, a new vehicle can be sent in to alleviate crowding.

In addition to GPS technologies, non-satellite based options can also be effective. For example, infra-red technology can track vehicle movements in a similar fashion utilising local beacons distributed through the public transport area. This type of technology can be an effective alternative when topography and tall buildings act to block satellite-based communications.

GPS became the preferred option for automatic vehicle location in the past years. Nevertheless there are other options such as loop inductors (*e.g.,* Los Angeles Metro Rapid System) and signposts (*e.g.,* London and Seattle). These technologies are based on non-continuous detection coupled with odometer readings (dead reckoning) and complex prediction algorithms. Costs of these systems are in the order of US$5,000 per vehicle (London signpost system) to US$14,000 per vehicle (Los Angeles Loop detector system). GPS systems cost, as reported in some applications around the world is in the order of US$750 per vehicle (Kaohsiung and Taichung) up to US$11,600 (San Francisco).

However, few of these technologies are "plug-and-play" applications providing easy, off-the-shelf solutions. Quite often a great deal of software programming must accompany the system set-up. Further, as a system expands and becomes more complicated, the underlying operating software will again require updating. The control centre for Bogotá worked adequately through the project's first phase. However, as the system expanded to double its first-phase size, the existing control system no longer functioned and required substantial re-engineering.

12.3.2 Traffic signal control

The development of a BRT system can also present a unique opportunity to upgrade the traffic signal technology along the same corridor. A new BRT system will imply several changes that will affect traffic signal technology. These changes include:

- New priority treatment for public transport vehicles;
- New exclusive lanes;
- New turning movements for public transport vehicles;
- New restrictions on private vehicle turns.

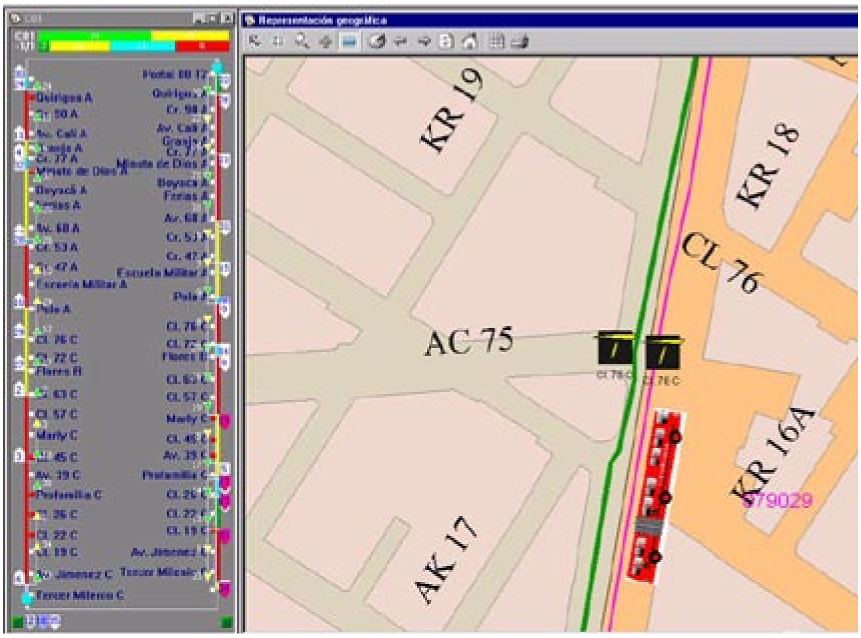


Fig. 12.70
Vehicle location software helps maintain efficient operations for TransMilenio.
Image courtesy of TransMilenio SA

These options have already been presented in detail in Chapter 9 (*Intersections and signal control*).

With new electronic signalling technologies and software programmes now available, an upgrade of the traffic signal system should be integrated into the BRT planning process.

The appropriate synchronisation of traffic lights often does not currently exist in developing cities. A readjustment of phase lengths and synchronisation should be undertaken with a special focus on smooth public transport vehicle flow. Some type of priority for buses can be introduced, such as "green extension" or "red shortening". In these options vehicle detection, either using the GPS or fixed detectors (*e.g.,* transducer), is required at the intersection. Information on arriving buses is given to the signal controller which can increase the green time or shorten the red time not to stop the buses. Green extension or red shortening is limited to by certain limitations so as to not affect signal synchronisation and the overall performance of the signal network. An extreme priority measure is signal pre-emption, where the signal turns green or remains green if a public transport vehicle is approaching. Pre-emption is quite commonly used in conjunction with priority for emergency vehicles.

Priority signal technology is an option, but is not always feasible in high-frequency systems. In cities such as Los Angeles, signal priority is given to public transport vehicles by way of a message relayed from a vehicle transponder to the signal control box (Figure 12.71). As a public transport vehicle approaches, the traffic light will extend the green phase to allow the bus to pass. However, even with relatively long peak headways of five minutes or more in Los Angeles, the signal prioritisation will only function every other phase cycle. If the phase priority is given more frequently, it will essentially give a permanent green to the direction of the public transport corridor. Thus, other vehicle directions will become unavailable.

In developing cities with high population densities, peak public transport headways may be in the range of one to two minutes. In such a scenario, signal prioritisation becomes less viable. Nevertheless, other improvements such as adjusting phase lengths are still quite possible in the developing city context. Chapter 9 of this Planning Guide elaborates on this topic.

Integrating traffic signal control into the centralised control system is also an option to consider. In cities such as London, traffic cameras at key intersections permit control centre staff to directly observe potential congestion points. This technology can be used to provide priority to public transport vehicles entering a bottleneck point.

Fig. 12.71
In Los Angeles, a transponder beneath the vehicle communicates with a control box at the intersection in order to give public transport vehicles signal priority.
Photo courtesy of the Los Angeles County Metropolitan Transport Authority

12.3.3 Real-time information displays

"All of the biggest technological inventions created by man—the airplane, the automobile, the computer—says little about his intelligence, but speaks volumes about his laziness."
—Mark Kennedy, politician, 1957–

Information technology is changing all aspects of daily life. Public transport has likewise benefited from the reach of information technologies as well as the continuing reduction in technology costs. "Intelligent transportation systems" (ITS) refer to a range of information technologies that provide more choices and better quality for the customer.

Real-time information displays are one application of ITS that can alleviate concerns over the reliability of a service. Information on the public transport vehicle's location can be relayed via several technologies to displays at stations informing waiting passengers of the next available vehicle (Figure 12.72). Real-time information helps to reduce customer "waiting stress", which affects passengers who do not know when or if a particular route is going to arrive. By knowing the expected arrival time of a bus, the customer can mentally relax as well as potentially under-

Fig. 12.72
A real-time information display in Berlin.
Photo by Lloyd Wright

Fig. 12.73
In Singapore, customers can view arrival times prior to entering the platform area.
Photo by Lloyd Wright

take another value added activity to make best use of the time.

Some systems, such as the Singapore MRT system, even place a real-time information display at the outside of the station (Figure 12.73). This allows customers to make best use of their time as well as helps reduce stress and rushing. A customer may see that they have several extra minutes prior to entering the closed station boundaries. In such a case, the customer may elect to run an errand or enter a shop to make a purchase before going to the station platform. Indicating the arrival times outside the station areas can also be an effective marketing tool. Exposing motorists and other non-users to the frequency of the system can help to attract new users.

In high-frequency systems where headways are three minutes or less, real-time information displays may be of less value. However, even in these circumstances, customers can be aided in making travel route decisions. For example, passengers may be in a position to decide between taking a local or express route. With the expected arrival times of both options posted, the passenger can determine which route is optimum from a travel time perspective. Also, in cases of a vehicle being quite full, a passenger may decide to wait for the next vehicle if it is only a few minutes away. In this sense, real-time information can help balance passenger loads naturally, and thus mitigate the system delays when vehicles are overly loaded.

Variable messages signs also post information when incidents occur, providing passengers with instructions and expected delays (Figure 12.74).

This type of information can also be useful inside the vehicle as well. A video or digital display inside the vehicle can list the next station (or even the next three stations) as well as the final destination of the route. In conjunction with a recorded audio announcement of the next station, customers can enjoy a more relaxed ride without having to repeatedly check their position. Passengers can undertake other value-added activities, such as reading, without worrying about missing their destination. Further, in crowded vehicles, consulting the posted system or route map can be difficult. The video and audio information helps persons easily gain information without jostling about the vehicle.

Similar types of technology can also be integrated with public transport security efforts. Security cameras both inside stations and vehicles are increasingly cost-effective approach to system policing. The mere presence of the cameras themselves is often associated with a reduction in criminal activity. The cameras are also a visible sign to the customer of system security and can help reduce anxieties, particularly amongst vulnerable groups.

Once the information of vehicle location and schedule compliance is gathered, there are many alternatives to convey the arrival information for passengers. As telecommunication technologies

Fig. 12.74
Electronic kiosks inside the stations of the Taipei BRT system keeps passengers informed.
Photo courtesy of Jason Chang

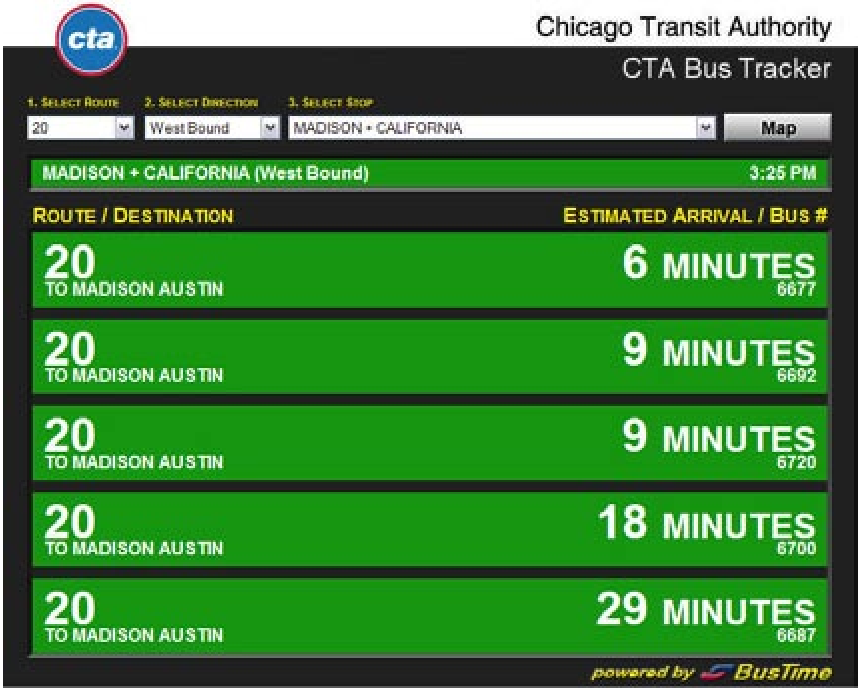


Fig. 12.75
In Chicago, public transport scheduling information can be downloaded from the internet or through text messaging.
Image courtesy of Chicago Transit Authority

advance there are opportunities to provide passengers with data via kiosk, Internet, SMS, Wireless PDAs and so on. Passengers can plan trips from home with scheduling and real time information, or just ask via cellular phone or wireless PDAs, when a public transport vehicle is arriving to a given location (Figure 12.75).

Overall, though, ITS can deliver substantive improvements to system efficiencies. With the cost of such systems falling each day, even developing nation cities should conduct a full review of the options and potential implications. For further information on this topic, TCRP Synthesis Report 48 is a useful resource (TCRP, 2003).

12.4 Equipment procurement process

The appropriate structuring of the procurement process can create a competitive environment that will drive cost reduction and efficiency. Additionally, a well-designed procurement plan will promote an open and transparent process that will help to eliminate corruption and graft. System developers should seek a wide range of bidders for each piece of equipment needed. To achieve this environment of competitiveness, the procurement specifications should be sufficiently rigorous to meet system requirements while also permitting bidding firms the ability to innovate. Prior to issuing tenders, an explicit set of criteria should be created that sets forth the determining parameters for selecting a bid and the relative weight given to each factor (cost, experience, quality, etc.). The determination of winning bids ultimately should be decided by an objective, independent body whose members have no commercial interest with the overall project and have no relationship in any form to the bidding firms.