

# BUS RAPID TRANSPORT AND URBAN DEVELOPMENT

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## ABSTRACT

This paper discusses the key elements of a modern design of a Bus Rapid Transit (BRT) system. Most travellers value the characteristics of metro, LRT and trams but not all cities can afford the high levels of investment and subsidies required to implement and operate them. This does not mean that these cities cannot design modern and high performance systems based on bus technology.

These BRT systems go well beyond conventional bus operations but their design requires careful consideration of the traffic engineering issues at bus lanes and stops/stations, priority at junctions, physical and fare integration and, above all, the willingness of customers to interchange.

The paper introduces some key elements of BRT design and uses the case of Transmilenio, in Bogotá, Colombia, to illustrate its advantages. There, a system costing € 5.3 per km is operating at high commercial speeds (around 27 km/h) and offering the high capacities needed (over 30,000 passenger per hour and direction). This is in contrast with metro and LRT systems costing considerably more.

This breakthrough in public transport technology is a result of a combination of factors: improved bus technology and design, improved understanding of the traffic operations at bus stops, the development of low cost control systems, the use of off-bus payment systems, fast boarding and alighting facilities, and detailed modelling techniques to assist the design of such systems to optimal performance.

## 1. TRANSPORT POLICY ISSUES IN AFRICA

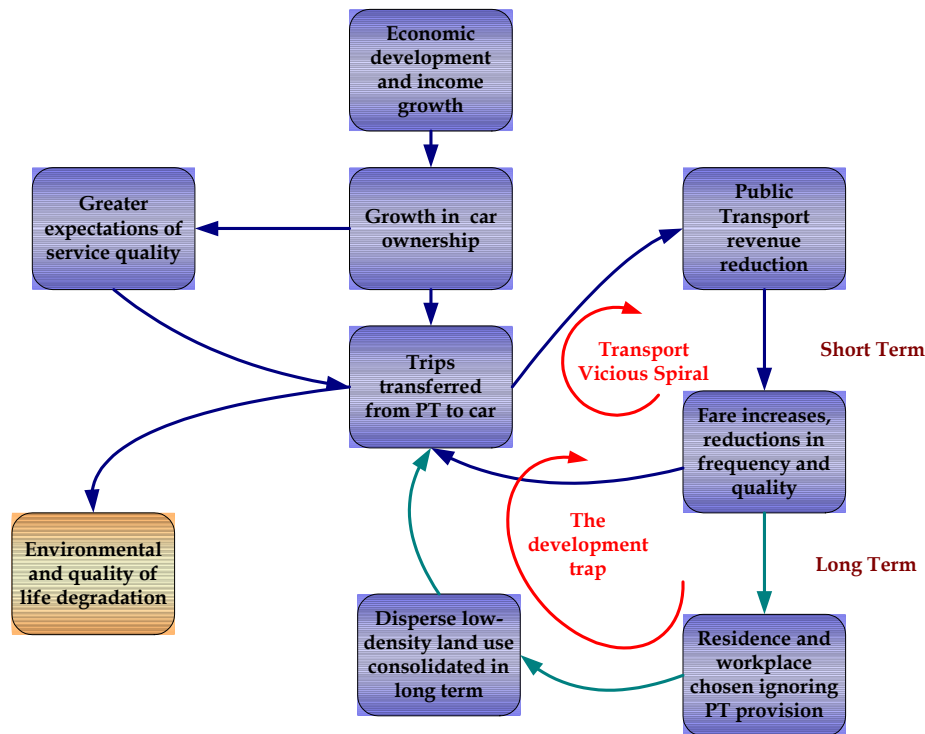
The first thing to notice is that Africa is very different from Europe or the USA. There are some features akin to Latin America, but in general terms, Africa offers its own challenges and opportunities that need to be resolved in a new way.

For a start, the level of car ownership is generally below to 10% in Africa in contrast with 48% in the European Community. In most of Africa the private car is still seen as somewhat of a status symbol and an indicator of progress. Despite the relative low levels of car ownership, road congestion can be very significant in large cities. This is of particular concern, as car ownership will rise with income levels putting even greater pressure on infrastructure and generating further delays and emissions.

A lot can be learnt from very successful experiences in Latin America. The most significant one is, perhaps, developments in high capacity bus corridors, what it is now called Bus Transit Systems. The Region has considerable experience in different forms of regulation and concession of public transport systems and has applied innovative policies in cities like Bogotá and Curitiba. The adoption and adaptation of new technologies is also quite

fast in Latin America: Santiago will have in 2006 more kilometres of free-flow urban toll road than any other region in the world and Sao Paulo, Bogotá and other cities use SmartCards to achieve fare integration.

The basic problem, how to cope with increasing car usage at a reasonable cost, remains as a key concern in the Region. The problem can be visualised in Figure 1, the Public Transport Vicious Spiral and its implications for land use and urban development.



**Figure 1. Public transport vicious spiral.**

There are, in fact, two “vicious circles” here, a short/medium term one and a long term one. In the short term, as incomes grow and more people choose to use their cars instead of public transport the operators have to reduce services, increase fares or both. This makes using the car even more attractive and therefore reinforces the public transport downwards spiral. Subsidies and car restraint measures may slow this down but are never able to revert the process.

In the longer term, the problem becomes more acute as car-owning families start to choose places of residence and work independently from the provision of public transport services. Developers find it easier to sell the “dream house” with garden and nice neighbours, regardless of the longer car journeys and wasted time spent in congested conditions. The de-coupling of home/workplace choices from transport provision results in low density housing that is too difficult to serve by public transport efficiently. This is the development trap, higher incomes and dream homes may result in stressed lifestyles and neighbourhoods that are too expensive to serve by public transport. The costs in wasted time, emissions and congestion externalities of this outcome are very considerable. The accumulation of rational individual choices results in an arrangement that is more expensive and less desirable both for the individual and society.

The double challenge of population and economic growth requires a more innovative approach. This must seek to:

- Provide the type of services required by car owners and non-car owners and recognise that these may well be different.
- Provide information and support for better decisions (especially in the longer term) on the part of the individuals.
- Internalise externalities so that individual decisions consider all relevant costs, to them and to society.

In our experience it has been established that car owners are more interested in the quality and reliability of public transport services than in their fare; attitudinal surveys in this segment often identify a Metro system as the only alternative worth considering. Lower income travellers, on the other hand, value low fares, access (shorter walks) and reliability over other quality features. How to provide differentiated services, each with the characteristics expected from different market segments, is one of the key challenges in transport policy in emerging countries.

A couple of ideas are offered in Figure 2. It is suggested that the provision of good public transport services combined with the pricing of externalities should help to arrest the PT Vicious Spiral. The avoidance of the Development Trap requires sensitive and enforceable land use policies and regulations coupled with an effort to increase the quality of travel decisions through awareness campaigns and programmes like Travel Blending.

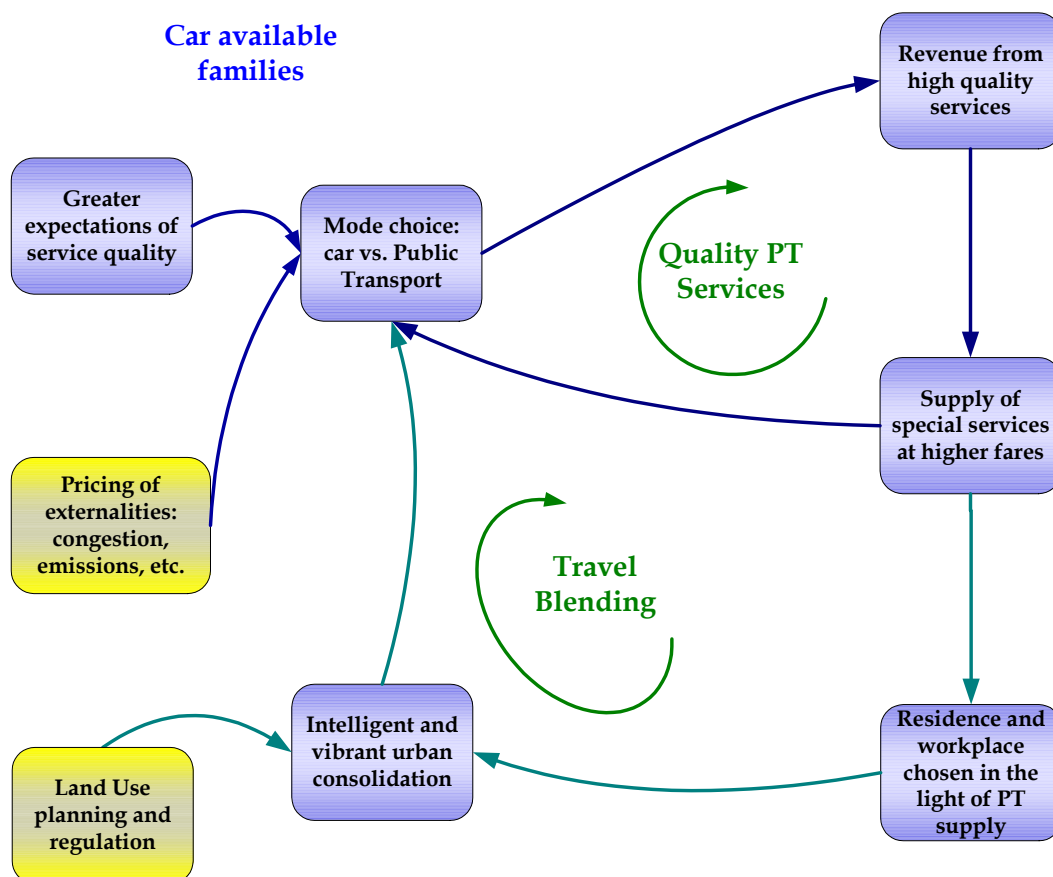


Figure 2. Measures to improve travel decisions.

## **2. LRT, TRAMS AND BUS SYSTEMS**

It is common knowledge that travellers value the quality of the public transport service provided to them. Everything else being equal, people prefer to travel by fixed-track systems, and they seem to prefer Rail to Metro and Metro over Light Rail Transit (LRT) or Trams. People value the comfort of the ride, the smooth acceleration and braking, the light and modern interiors and external appearance of trams and LRT.

This preference for LRT and trams has been one of the driving forces behind their resurgence in Europe. Even countries like the UK, who had more or less abandoned its trams, restarted implemented them in the early nineties with several systems now in operation.

LRT and trams are valued above bus systems, but they also cost more money in terms of investment and (often) operating costs. It is relevant, therefore, to ask how much greater is, in the perception of travellers, the value of a tram or LRT compared to a bus system.

The answer to this question (how much more desirable is a fixed-track system) has been thoroughly researched using Revealed and Stated Preference techniques. In our own work, we have been able to determine that in the economic and cultural context of the British Isles, a fixed-track system has a modal premium of the order of 2 to 15 generalised minutes over a conventional bus system. We have found values in the lower end of this range for travellers without a car available to them, whilst the upper range is for car-available higher income travellers

The other characteristic associated with trams and metro systems is superior capacity and performance. There is little question that fully segregated metro systems offer greater capacity than anything running on the surface. This is because of the shorter times at stations required to board and alight a large number of passengers. This is helpful, as the large investment required to implement metro or LRT must be distributed over a large number of beneficiaries to be justified on economic grounds.

Many cities have decided that they have sufficient levels of demand to make it worthwhile investing the large sums of money required to implement metro or LRT systems. This is not always accompanied by the corresponding willingness the pay the higher levels of fares that would be required to recover the original investment. This is one of the reasons why LRT systems are seldom fully funded by the private sector; there is often the requirement for major contributions from the local authority and/or central government.

Most of the tram and LRT systems mentioned above have benefited from contributions from the public sector but have been implemented in collaboration or partnership with private companies and banks. Even in Britain, where travellers are used to higher fare levels than in Continental Europe, LRT systems would not be possible without a significant contribution to capital costs by the public sector. This contribution (grant) is often justified on the basis of the positive externalities of these systems: decongestion benefits, reduced emissions and accidents and, in particular, assumed economic regeneration effects.

## **3. THE CASE FOR BUS TRANSIT**

Despite their advantages, the higher capital and operating costs of trams and LRT make them inadvisable in many cities. This does not mean that these cities have to accept conventional bus systems as the only alternative. There are a number of intermediate options where bus systems are enhanced to provide a better alternative. They all tend to

use bus technology combined with advanced design features to achieve high performance; the best known current example is the Transmilenio system in Bogotá ([www.transmilenio.gov.co](http://www.transmilenio.gov.co)).

These systems have in common an effort to design a low cost but high quality public transport system based on bus technology but with significant enhancements to deserve the name of Bus Rapid Transit (BRT). It has been possible to establish that a well designed BRT system can be valued nearly as much as a tram system, for example having a modal premium of around 7-10 minutes compared with conventional bus services. On the other hand the capital costs are often a fraction of the cost of rail-based systems. As buses are easy to operate and maintain, the running costs of such systems are also affordable and generally lower than LRT. The following Table 1 compares some of the key characteristics of LRT and Bus Transit Systems.

**Table 1. Comparison of different rapid transit technologies.**

Characteristic	Tram -LRT	Metro	Bus Transit
Capacity (Pax/veh)	110-250	140-280	80-160
Vehicles/unit	1-4	1-10	1
Maximum Speed (km/hr)	60-80	70-100	60-70
Commercial Speed (km/hr)	15-35	25-55	15-28
Maximum Frequency at stops (units/hr)	40	20-40	70-210
Capacity at stops (pax/hr/direction)	6,000-20,000	10,000-72,000	11,000-40,000
Capital costs (€ M / km)	15-50	30-200	1-10

(Estimates from our own experience)

The high values for capacities and commercial speeds for BRT may surprise some practitioners. These are not theoretical values but observations on existing operating systems in the last few years. Recent developments in the design of BRT systems have enabled these high performances; we will discuss some of these elements later on.

The value that people seem to associate to Bus Rapid Transit (BRT) systems can be seen as partway between a metro or LRT and a simple high quality bus service. In fact, some BRT systems like Transmilenio are perceived as very similar to an LRT system because of the greater investment in infrastructure and the efficiency of the system as measured by their commercial speed.

There is, therefore, a whole range of BRT technology options that are capable of delivering a wide array of service levels. Very often, the justification for BRT is part one of cost, in particular capital ones, but also partly one of flexibility and speed of implementation. Transmilenio, again, was implemented and running commercially in less than 18 months from completion of the original study.

The US Federal Transit Administration is embarking into a major programme to support BRT demonstration projects. However, the materials they have produced are of relevance only to systems designed for low levels of demand, as is typically the case in the USA. This paper is concerned mostly with BRT applications in the European context, with different requirements and specifications. Therefore, it focuses on high performance-high capacity systems where Transmilenio provides a relevant example.

## 4. BUS RAPID TRANSIT TECHNOLOGY ISSUES

### 4.1 Introduction

A high-performance BRT system is characterised by a set of characteristics that enables them to provide:

- High commercial speeds to reduce in-vehicle travel times. The main reasons for in-bus delays are congestion from other vehicles, number of stops en route, delays at stops due to boarding and alighting, delays at stops because of interference from other buses when frequencies are high, and delays at junctions.
- High frequencies to reduce waiting times. These possibly require grouping of services and careful design of network and operational features. Passenger information systems may also reduce delays and their perception.
- Good penetration into areas of demand to reduce access times. This is facilitated by good route design and particular operational arrangements, for example trunk and feeder services with smaller vehicles.
- Good infrastructure design to improve safety and attractiveness of the system, plus quality vehicles to provide a better ride and enhance service levels.

In order to achieve these desirable system characteristics, the whole BRT system has to be designed in a coherent and consistent manner. The design can be seen as affecting three key elements: (a) Infrastructure and Technology Issues, (b) Operational Issues and (c) Customer and Planning Issues. We will discuss each in turn using Transmilenio as an illustration.

### 4.2 BRT Infrastructure and Technology Elements

These elements include:

- The **track** or carriageway. This could be a simple bus lane with some physical segregation or a guided track as in the case of O-Bahn systems in Adelaide and Essen. Double segregated bus lanes are needed for high capacity systems to allow overtaking. As the critical capacity is encountered at stations, BRT often have double lanes at them to permit overtaking.
- **Junctions**. These could be treated with lower cost priority for buses at traffic signals or more expensive grade separated junctions that avoid all conflicts.
- **Stops and stations**. All BRT require a stop similar to those designed for LRT systems. They could just be a better shelter like in the case of Leeds Quality Bus or a safer, better-controlled station as in Curitiba and Transmilenio where passengers pay on entry to the station and then board buses at level through all doors.
- **Pedestrian access** to stations. This could be through simple zebra or signal controlled level crossings or via safer pedestrian bridges as in Transmilenio.
- **Vehicles**. These are often high performance articulated buses; bi-articulated buses are used in Curitiba and simple articulated buses in Transmilenio). For pay at station systems the buses and the stations are high platform to facilitate enforcement. In Transmilenio the stations are in the central reservation and the buses have doors on

the left, at the same side of the driver, to facilitate docking and enforcement. Occasionally, the vehicles may be trolley-buses, as in the case of Quito.

- **Service Control and Passenger Information Systems.** This is not always required but it is reasonably low cost to offer. Control systems in Transmilenio are based on GPS and PC terminals; there is no real-time passenger information system yet given the high frequencies of operation.
- **Ticketing.** This is important and most delays happen at stations/stops and therefore in order to achieve high performance it is necessary to enforce pay-before-boarding policies. Transmilenio uses Smartcards with payment on entry to the station or on boarding feeder services.

The provision of special facilities to cycle users (cycle and ride) and to assist those reaching stations on foot and the disabled are also of significant importance.

#### 4.3 Operational Design Elements

Here the key issues are the route structure, service pattern, service frequency, distance between stops, and integration with other services.

- The route structure defines where the services will run and how the routes will complement each other. A typical route pattern is to develop a trunk and feeder service network, similar to that adopted in many LRT and metro systems.
- Service pattern. In high performance trunk sections sometimes it is necessary to run a combination of express and stopping services in order to reduce conflicts at stations and provide faster services. For operational reasons, an alternative arrangement is to run the buses in convoys; the best example of this arrangement is in Porto Alegre. However, it is recognised that it is difficult to retain the convoy operation so this approach is now seldom adopted.
- Service frequency. People would prefer services that are instantly available and carry them from origin to destination without interchange. This is not practical and therefore compromises are needed. In order to retain high frequency, services have to be grouped and interchanges facilitated at key stops. Transmilenio achieves this by using smaller buses for feeder services, special interchange stations and long platforms at trunk lines to facilitate transfer along the platform.
- Distance between stops. Stops are seldom closer than every 400 metres as frequent stops increase delays. On the other hand, if stops are too widely spaced access to the services is reduced. The best compromise depends on local conditions and demand patterns.
- Integration with other services. The BRT may already contain many elements of integration, for example in trunk and feeder services. The operators, however, may be part of separate companies and concessions. Careful design and good fare integration is required to achieve maximum integration across all public transport services. In some European countries this integration includes local taxi services in low-density areas.

#### 4.4 Customer and Planning Interface

The elements here must assist the perception of an integrated and attractive service and influence the development of active land uses in the vicinity of the stations and stops.

- Marketing and Architecture. These are, of course, separate issues but people value consistent and attractive architecture and a marketing approach that generates interest and “buy in” of the new service. Savings in these two areas would be a significant mistake if the plan is to promote BRT as a key structuring service in a city.

- Fare strategy. The advantages of full integration have already been mentioned. Modern technology facilitates this with non-contact Smartcards and a variety of other payment methods. The systems may be adapted to allow m-commerce (pay through mobile phones) approaches in the near future. Seasonal tickets and special discounts off-peak are also part of an intelligent fares strategy.
- Passenger information systems were already mentioned as part of the technology issues. A consistent design of good quality maps and visual communications is also of great importance. The use of SMS, and locational-based services later on, will facilitate dissemination of the right information to the right person at the right time at minimal cost.
- Safety and Security are important components of the attractiveness of a system, whatever the technology. Perhaps surprisingly, Transmilenio has contributed on both grounds in a difficult location like Bogotá, Colombia.
- Planning and regeneration. It is argued that in order to structure the urban development of a city, or to regenerate an area, it is necessary to invest in major visible infrastructure. It is true, for example, that the Docklands Light Rail played a positive role in the regeneration of that area of London. The introduction of a BRT system with consistent architecture, well designed stations, secure services and well-implemented track segregation can have a similar effect; as it did in structuring the fast development of Curitiba in Brazil.
- Partnership with Private Sector. This is not an essential part of a BRT system but may help significantly in the efficient operation and delivery of an innovative and high quality service; good design of contractual documents and performance indicators is needed.

## **5. HIGH PERFORMANCE BRT**

This section discusses the key elements to achieve high capacity and performance for Bus Rapid Transit systems. The analysis is based on the concepts of capacity and commercial speeds.

The commercial speed along a particular corridor served by BRT depends on the following characteristics of the service:

- Speed while moving
- Delays at junctions
- Time spent at stops
- Number of stops

Speed while in movement depends on the design of the trackway, the characteristics of the vehicle and the number of stops that affects acceleration and deceleration. Delays at junctions are dependent mostly on junction design. The number of stops en-route is a critical element depending on the operational design: stopping and express services, trunk and feeder arrangements.

We will focus here on the time spent at stops and the capacity of simple stops as these have a very significant impact on overall performance; they are the building block to the design of high performance BRT.

The capacity of a single bus stop/bay is controlled by the time spent at it to load and alight passengers and perform the arrival and leaving manoeuvre. If the time spent at a stop is, say, 30 seconds, its capacity will be 120 buses per hour. However, bus arrivals are not regular and therefore queues to enter the bus stop occur with bus flows much lower than



120 buses/hr. In line with other Traffic Engineering concepts we may call the ratio of demand (buses/hr) over capacity the Degree of Saturation  $X$  of the bus stop.

Evidently, it is not desirable to have buses queuing to enter a bus stop and therefore we must design for a relatively low degree of saturation, typically 0.40. The maximum frequency at a bus stop will depend on the time spent at the stop ( $t_s$ ) and this maximum degree of saturation. The capacity in passengers an hour will depend on the carrying capacity of a bus,  $PaxB$ . For  $X_{max} = 0.4$  the maximum frequency ( $f_{max}$ ) and the operational capacity ( $C_p$ ) in passengers per hour at a stop will be given by:

$$f_{max} = \frac{0.4 * 3600}{t_s} = \frac{1440}{t_s} \quad \text{and}$$

$$C_p = \frac{1440 * PaxB}{t_s}$$

Larger bi-articulated buses offer larger  $PaxB$  that increase bus stop capacity. The remaining and key element is the time spent at a stop.

This is made up of two elements:

- $t_0$ , the dead time per vehicle: this is the time required to arrive, open doors, close doors and exit the stop. Depending on local conditions this is between 8 and 15 seconds per stop.
- $t_p$ , the average time required per passenger to board or alight. This will depend on the number of doors used, height of platform/floor and whether passengers pay on boarding or in another manner.

Table 2 shows the values of operational capacities for different types of vehicles, bus platform and forms of payment. It can be seen that the maximum capacity is offered by bi-articulated buses, high platform level boarding and pay off-bus, in fact on entry to the bus station.

**Table 2. Operational capacities of different bus types and stops.**

Vehicle & Operation	$PaxB$	$t_0$	$t_p$	Capacity	
	pax	seg	seg	Pax/h	Veh/h
Mini-bus, pay driver	15	10	3.0	1,137	76
Midi-bus, pay driver	35	11	3.0	1,575	45
Bus, pay driver	70	12	3.0	1,867	27
Articulated + pay to conductor	160	13	1.5	3,777	24
Bi-articulated + conductor	240	14	1.5	4,019	17
Articulated, high platform + cond.	160	13	1.0	5,120	32
Bi-articulated, high platform + cond.	240	14	1.0	5,574	23
Articulated, high platform, pay off-bus	160	13	0.3	9,779	61
Bi-articulated, high platform, pay off-bus	240	14	0.3	12,169	51

Clearly, other combinations of payment, bus size and platform height are possible. In the case of Transmilenio we used our experience of bus operations in the UK and Brazil to choose articulated buses with high platform level boarding and payment off-bus. The problem we had was that demand on the Caracas corridor was already above 40,000

passengers per hour and direction during peaks. The table above shows that this cannot be met even with articulated buses, an argument often used to justify rail based public transport.

We looked at combining buses in convoys, as in Porto Alegre but concluded that with this approach we could only increase capacity to 20,000 passengers per hour and direction.

It was necessary therefore to incorporate the following design features:

- Express and stopping services so that buses did not stop at all locations. Good interchanges along longer platforms were therefore needed.
- Designing stations with long platforms at critical points to cope with up to four buses stopping simultaneously.
- Design stopping areas with double bus lanes to allow overtaking by express services and the immediate departure of buses when completing their stop operations.

With this type of arrangement we planned for capacities of up to 35,000 per station and higher when considering non-stop buses operating on that section. The planned and achieved commercial speeds were of 27 km/h, comparable to most LRT systems costing considerably more.

## 6. OVERALL DESIGN ISSUES: TRANSMILENIO

The introduction of a BRT system in a city often involves a major change in the public transport routes and service patterns. It is important to ensure, therefore, that the change is perceived as a major improvement in travel conditions. As we have seen before, the design of a BRT system involves a number of decisions regarding routes, operational patterns, interchange locations, ticketing and so on. It is important to ensure that all the design elements are chosen within the context of very good information on current service levels and demand patterns.

In the case of Bogotá, Colombia, the pre-Transmilenio system had over 20,000 registered buses of at least six different types, with capacities ranging from 15 to 72 passengers per unit. They were all operated by small, mostly one bus, private firms. The quality of service was poor but frequencies were high. Most journeys were undertaken without transfers as they required the payment of an additional fare. The longest and more expensive trips were made by lower income residents living in the outskirts of the city.

In order to design the new system we undertook extensive data collection including frequency and occupancy surveys (250,000 records), On/off surveys (20,000), Origin Destination surveys (66,000) and passenger counts at stops (3,000). We also undertook detailed Stated Preference surveys to obtain key parameters like the relative importance of walking, waiting and on-bus times, transfer penalties and BRT premium, if any. A detailed Emme/2 model was developed for the city, including private cars and a possible metro system. It is important to use an appropriate model capable of allocating travellers reliably to services on routes with common sections; Emme/2 powerful public transport assignment features were used to obtain reliable service passengers and revenues, optimise fares and reorganise the rest of the bus services.

The comparison between services with and without Transmilenio were undertaken on the basis of the generalised cost of travelling between each Origin Destination pair:

$$GenCost = a_1 t_{access} + a_2 t_{wait} + a_3 t_{onbus} + a_4 TotFare + n \tau_{trans} + \delta$$

Here  $a_1$ ,  $a_2$  and  $a_3$  are the weights attached by a segment of travellers to walking, waiting and on board times. The ratio  $a_1/a_3$  is often described as the Value of Travel Time Savings. **TotFare** is, of course, the total fare to be paid from Origin to Destination and  $n\tau_{trans}$  is the total number of transfers multiplied by the transfer penalty; finally,  $\delta$  is the modal premium, if any. Our model was able to identify generalised costs for different segments of the market as a function of their willingness and ability to pay for a better service.

The full design of the system involves an iterative process as different options, including fare levels, attract different types of customers. The final design involved the adoption of seven trunk corridors in Bogotá, each with its own feeder service concessions for their catchment areas. Three of these corridors were put in operation within 18 months of completing the study. The trunk corridors involve single and double segregated exclusive bus lanes, stations in the median, articulated buses with doors on the left, pay on entry to the station using SmartCards, a GPS control system and major interchange stations and terminals for storage and maintenance. The system has been given in concession, its flat fare of €0.40 covers its operating and vehicle costs but the infrastructure was funded by the Public Sector. All Bogotanos perceive Transmilenio as a major success that has improved not just the transport system but also contributed to better safety and quality of life.

The average infrastructure costs are €5.3 million per km. The main benefits were significant savings in travel times, accidents and emissions.

The Transmilenio design has been found to be appropriate to the conditions in Bogotá. It may work well in similar cities, with very high levels of demand and where it is still possible to fit double bus lanes each way in some critical sections. The African context provides a few cities with these characteristics. There are, indeed, design projects underway in Cape Town, Dar es Salaam and, in the near future, in Lagos.

In Latin America, there are several projects underway in at least Brazil, Chile, Colombia, Mexico and Perú. Perhaps not all of them will be entirely successful, as there are already poor imitations of some features of Transmilenio in Jakarta and other places.

However, what Transmilenio has been able to prove is that recent advances in technology (buses, ticketing and control) and transport system design know-how, have created a complete range of affordable and attractive alternatives to LRT. These are worth considering either as precursors of a future LRT (securing a valuable right of way) or to provide an early high quality and urban structuring public transport system.