CHAPTER 11
Trunk Bus Operation Plan

11. TRUNK BUS OPERATION PLAN

11.1. OUTLINE OF PROPOSED TRUNK BUS SYSTEM

The trunk bus system is proposed to cope with four major problems, among others, of public transportation in the study area: namely, (i) reduced bus operating speed during peak hours, (ii) pronounced congestion of bus traffic caused by the concentration of bus lines, (iii) the failure thereby of providing regular bus service on schedule and (iv) the difficulty of maintaining the functional and efficient bus operation, as seen in the extremely low occupancy rate of buses within the Centro. The benefits accruing from the trunk bus system to the bus operation in particular and the transportation in general are discussed in Chapter 10. This chapter describes in detail the trunk bus operation system in the study area, including its relationship with the conventional bus lines.

11.1.1. PROPOSED TRUNK BUS SYSTEM

Salient characteristics of the proposed trunk bus system are summarized in Table 11.1-1, and details of the operation plan are presented in Table 11.1-2.

(1) Bus Operation System

The future bus transportation consists of three system components: namely, (i) trunk bus system, (ii) feeder bus system and (iii) conventional bus system. Taking into account the different busway facilities conditions, the proposed trunk bus system runs on three types of busways: viz., (i) trunk busways, (ii) exclusive trunk busways and (iii) trunk bus priority lanes. A feeder bus system is provided for relatively short rides to collect passengers to each trunk bus terminal with integrated transfer. The trunk bus system replaces 61 conventional bus lines, and the remaining 104 bus lines continue their conventional service.

(2) Introduction of Integrated Bus System

The present study proposes eight new bus terminals for trunk bus operation. Each terminal provides integrated transfers between feeder and trunk bus lines. In this proposal, conventional bus lines will not be integrated with the trunk bus system. Accordingly, eight bus terminals will be so structured to segregate the integrated feeder and trunk bus services from the conventional bus lines and other private transport means. Passengers of conventional bus lines can transfer to trunk bus lines at trunk bus stops but they have to pay the fare again. Passengers of a trunk bus line also have to pay the fare whey they transfer to another trunk bus line (A bus zone to/from B bus zone) at a trunk bus stop.

Three trunk bus terminals (designated as A, B and C) are constructed along Rodovia Augusto Montenegro to service passengers traveling between Icoaraci and the Belem Centro. The remaining five terminals (designated as C, D, E, F, G and H) are constructed along Rodovia BR-316 and Avenida Independencia to connect Ciudade Nova and Marituba respectively to the Centro. To fully realize the passenger benefits and the efficiency of bus operation, it would be much better to integrate the service network of all eight terminals into one. However, the present study proposes a feasible short-term alternative of dividing the trunk bus system into two service zones. Namely, Terminals A through C form one zone (A bus zone) with integrated transfers between them, while Terminals D through H are integrated into another zone (B bus zone). The fares are not integrated between two service zones (See Chapter 8 for details).

(3) Management and Organization of Trunk Bus Operation

29 private companies currently run 165 conventional bus lines in the study area with the authorization and supervision of CTBel of Belem City and DEMUTRAN of Ananindeua City. The proposal of the present study consists of the co-existence of the integrated trunk-feeder bus service and the conventional bus service as separate systems, on the one hand, and the development of special facilities such as busways and terminals for the trunk-feeder bus system, on the other. In conjunction, the present study proposes the institutional development to introduce the trunk-feeder bus system and implement the necessary infrastructural development as early and smoothly as possible (see Chapter 19 for details).

(4) Development of Bus Infrastructure

In order to ensure the smooth and effective operation of the trunk bus service, the present study proposes the following infrastructural development.

1) Two-way trunk busways are constructed on the central part of three existing trunk roads, namely, Rodovia BR-316, Avenida Almirante Barroso and Rodovia Augusto Montenegro. In conjunction, the available roadways, bikeways and sidewalks of the three roads are structurally improved.
2) Avenida Independencia, two-way four-lane road now under construction, is widened to a six-lane road with the two-way exclusive trunk bus lanes provided on its median.
3) Along a number of roads within Belem and Icoaraci Cities and Avenida Mario Covas in Ciudade Nova, an outermost lane on each side is improved as trunk bus priority lane, marked by colored asphalt concrete pavement.
4) Avenidas Pedro Cabral and Senador Lemos, currently serving two-way traffic with dual carriageway, are converted to one-way roads with three lanes, with the remaining lane improved as trunk bus priority lane, similarly marked by colored asphalt concrete pavement.
5) Integrated bus terminals are newly constructed at eight locations.
6) New bus stops are constructed along trunk busways and exclusive trunk bus lanes.
7) Existing Sao Braz Bus Terminal, currently serving long-distance buses, is converted to the intra-city transfer bus stop facility between the trunk and the conventional bus service.
8) Trunk bus traffic signals are installed at every major intersection along the trunk busways, exclusive trunk bus lanes and trunk bus priority lanes.
9) The trunk bus priority lanes are replaced from the asphalt concrete pavement to cement concrete pavement at major intersections inside Belem Central Area.

(5) Traffic Control for Bus Priority Lanes

The trunk bus operation will be manageable with relative ease on the structurally segregated trunk busways and exclusive trunk bus lanes, because it is less likely to affect the other vehicular traffic. The situation is entirely different on trunk bus priority lanes within cities, because (i) trunk buses use the same roadway as the other vehicular traffic, (ii) they are given priority only during the designated peak hours and (iii) they have to cope with various vehicles going to and coming from the roadside business establishments and residences. In order to overcome the expected difficulty of traffic management along the roads with trunk bus priority lanes, the present study recommends that the police supervise the strict observance of the traffic regulation until the residents at large acknowledge the need and the benefit of such observance.

Table 11.1-1 Outline of Proposed Trunk Bus System

System Component	Trunk Bus System			Feeder Bus System	Conventional Bus System
	Trunk Busways	Exclusive Lanes	Priority Lanes		
Traffic Condition	Exclusive all day	Exclusive during 6:00- 20:00	Priority given during 6:00- 20:00	Current system of mixed traffic	Current system of mixed traffic
Fare	Integrated system	Integrated and current systems	Current system	Integrated system	Current system
Distance between Bus Stops	Approx. 800m	Approx. 800m	Current distance of about 400m	Current distance of about 400m	Current distance of about 400m
Bus Stop Location	At major intersections	At major intersections	Current locations	Current locations	Current locations
Location on the Roads	Central part (median) of the roads	Central part (median) of the roads	Existing right-side lanes	Existing right-side lanes	Existing right-side lanes
Roads for Introduction	Av. Almirante Barroso, Rod. BR-316, Rod. Augusto Montenegro	Av. Independencia	Selected roads in the centers of Belem and Icoaraci Cities	Roads around new trunk bus terminals	Roads used by existing bus lines
Structure	Completely segregated by the concrete divider from the roadway	Partially segregated by chatter bars from the roadway	On the same roadway level	On the same roadway level	On the same roadway level
Bus Lanes	One lane each per way	One lane each per way	One lane each per way	Mixed with other vehicular traffic	Mixed with other vehicular traffic
Pavement	Concrete	Asphalt	Colored asphalt	Existing pavement	Existing pavement
Bus Type	Articulated double body type (200-passenger capacity)	Articulated double body type (200-passenger capacity)	Articulated double body type (200-passenger capacity)	Medium bus type (70-passenger capacity)	Existing bus type (110-passenger capacity)
Operation & Management	New organization created by pooling resources	New organization created by pooling resources	New organization created by pooling resources	New organization created by pooling resources	Existing companies
Terminals	Six new terminals	Two new terminals	------------	Eight new terminals	Existing terminals
Terminal Operation	Integrated	Integrated	------------	Integrated	Current system

Table 11.1-2 Trunk Bus Operation Plan

Operational Item	Description
Number of Bus Lines (routes) per Terminal of Origin	Terminals 2007 2012 / Terminals 2007 2012 A 2 4 / E 2 4 B 2 4 / F 2 3 C 1 2 / G 1 4 D 2 3 / H 2 4
Characteristics of Bus Lines	Those lines that pass Av. Almirante Barroso: As per terminal of origin, one line operates inside the Belem Centro, and the other stops at Sao Braz Terminal to go back to the terminal of origin. Those lines that pass Av. Independencia: As per terminal of origin, one line operates inside the Belem Centro, and the other stops at Avenida Visconde de Souzo Franco to go back to the terminal of origin.
Operation between Terminals Sharing the Same Trunk Bus Route	Trunk buses originating from Terminal A stop at Terminals B and C on their way to the Centro, and their passengers can alight at either one of these terminals. However, passengers waiting at the latter two terminals cannot board the buses originating from Terminal A. The same applies to the reverse direction from the Centro to Terminals C and B. The same relationship stands among Terminals D, E and F, and between Terminals G and H.
Headway per Line during Peak Hour (minutes)	Terminals / 2007 / 2012 A / 8.2 and 8.5 / 10.0, 16.0, 9.9 and 9.1 B / 9.5 and 10.4 / 11.0, 33.6, 9.8 and 27.7 C / 8.2 / 18.2 and 54.8 D / 3.9 and 12.7 / 3.2, 27.5 and 73.1 E / 6.3 and 29.8 / 6.2, 11.7, 14.8 and 6.5 F / 3.6 and 4.1 / 4.9, 3.8 and 4.7 G / 4.7 / 6.0, 13.6, 9.2 and 48.0 H / 4.0 and 4.7 / 5.2, 6.4, 13.5 and 8.9
Bus Fare	Fixed fare system (current system)
Fare Payment	A passenger does not pay in cash in the bus, but give a ticket or coupon per ride, or use a term pass or some type of card. New ticket registers are installed on trunk buses.
Sale of Tickets, Coupons, etc.	Tickets, coupons and so on are available at shops, kiosks and other outlets provided at or near trunk bus terminals and bus stops.
Passenger Boarding and Alighting	An articulated double-body bus has four doors, two doors per body. A passenger boards the front car through the front door, and alight through the back door.
Integrated Transfer	1) Trunk and feeder buses are integrated at each trunk bus terminal. 2) Passengers can transfer from one trunk bus line to another at each trunk bus terminal within the same service zone. 3) No integrated transfer is possible at trunk bus stops between bus lines, including both trunk and conventional. 4) The trunk and feeder bus system is not integrated with the conventional bus system.
Procurement of Articulated Buses	1) The trunk bus service in the first year of 2007 uses a fleet of paired conventional buses. 2) Starting from 2008, 28 articulated buses are annually purchased to replace the paired conventional buses. 3) Starting from the year 2018, 34 articulated buses are purchased annually.

11.1.2. EXPECTED BENEFITS OF TRUNK BUS SYSTEM

The expected benefits of the trunk bus system to the transportation sector are discussed in detail in Chapter 10. The benefits of the system are summarized in this section by category of beneficiaries. The description below compares the “with project” situation with the “without project” situation respectively forecast for the years 2007 and 2012. The results of economic and financial analysis on the proposed project are presented in Chapter 20.

(1) Benefits to Bus Passengers

1) Reduced Commuting Time

The average travel time of bus passengers was 28.1 minutes in 2002 in the study area. The “without project” forecasts for 2007 and 2012 are 41.2 and 53.5 minutes, substantially longer than the current situation because of the expected growth of transportation demand

and the resultant worsening of traffic congestion. The "with project" forecasts indicate significant improvement. The average travel time of 32.7 and 37.2 minutes in 2007 and 2012 is lower by 8.5 and 16.3 minutes respectively than the "without" forecasts. Commuters by bus in 2007 and 2012 will be able to save about 10 to 20 minutes one way by the introduction of the trunk bus system.

Average bus passengers spent approximately 80 minutes to travel from Icoaraci to the Centro of Belem City during the peak hours in 2002. The travel time in the "without" forecasts will rise sharply to 110 and 150 minutes in 2007 and 2012 apace with the rapid increase of motorized traffic along the bus route. By the trunk bus operation, the average travel time will be more or less halved to 60 and 70 minutes respectively in 2007 and 2012.

Average bus commuters from Marituba needed about 70 minutes to reach the Centro of Belem City during the peak hours in 2002. Their travel time will be lengthened to 110 and 140 minutes in 2007 and 2012 without the trunk bus system. By the innovation of bus transportation, they will be able to commute to the Centro in 50 and 60 minutes, an undeniable improvement on the "without" situation.

2) Merit of Regular Operation Bus Service

The peak-hour bus traffic on Avenida Almirante Barroso totaled as many as 610 vehicles in 2002. One bus every five seconds is no doubt extreme congestion. The proposed trunk bus system will provide its service with the headway of 5 to 10 minutes per line from each terminal and adequately meet the growing commuter demand. It is forecast that the peak hour bus traffic on Avenida Almirante Barroso will decline to 400 vehicles (250 conventional buses and 150 trunk buses) in 2007. The introduction of the trunk bus system will serve to alleviate the traffic congestion in the Centro in no uncertain measure, and realize the dearly needed regular operation bus service on schedule.

3) Reduced Waiting Time at Bus Stops

The bus passenger survey conducted in 2002 found that approximately 50% of bus passengers had to wait more than 10 minutes at bus stops, and that 10% or so even waited more than 30 minutes. The introduction of the trunk bus system will cut down the waiting time to 5 to 10 minutes.

(2) Benefits to Bus Companies

1) Reduced Expenditure on Bus Fleet

The trunk bus system will replace 61 existing conventional bus lines. Without its introduction, 446 new conventional buses must be purchased by 2007 to meet the expected growth of demand. With the introduction, the requirement will be down to 150 trunk buses (articulated double-body type), which is equivalent to 300 conventional buses. This means a sizable saving of the expenditure on the bus fleet. Without the trunk bus operation, the said bus lines will require the purchase of 548 conventional buses by 2012. The fleet size will be reduced to 213 trunk buses, equivalent to 335 conventional buses, if the trunk bus system replaces the conventional bus lines. This again means a large saving on the part of the bus companies.

2) More Efficient Bus Operation

According to the bus passenger survey conducted in 2002, the passenger occupancy rate reached as high as 80to 100% in the suburbs, but it was extremely low inside the Centro at around 5% to 10%. This inefficiency of bus operation will be lessened by the introduction of the trunk bus system, which provides two access routes to the Centro for the trunk buses originating from each of the proposed eight terminals. The occupancy rate of trunk buses within the Centro is estimated to range from 10 to 15%. This will enable the bus companies to run their bus operation more efficiently and effectively by reorganizing their operation frequency and fleet management.

3) Transfer from Private Cars to Bus Transportation

The proposed trunk bus system will markedly improve the public transportation available for commuters, by reducing the average commuting time and providing the regular operation service on schedule. In the foreseeable future, commuters by private car will predictably find it increasingly time-consuming to drive to their places of employment apace with worsening traffic congestion. Some of those motoring commuters are expected to transfer to bus transportation. The regular and stable trunk bus operation is likely to stimulate the potential demand for bus transportation. On the basis of the bus passenger survey findings in 2002, it is estimated that about 7% of car commuters are willing to use bus transportation during peak hours. An increased demand will be a definite plus to the bus company.

(3) Benefits to the Public at Large

1) Alleviation of Traffic Congestion in the Centro

The traffic survey in 2002 found that the average daily traffic congestion ratio (V/C=actual traffic volume divided by road capacity) was 0.5, yet a moderate level. Without the trunk bus system, the traffic congestion ratio will rise to 0.7 and 1.0 respectively in 2007 and 2012, because the motorized traffic is estimated to grow rapidly over the period. The trunk bus operation will considerably ease the situation, with the traffic congestion ratio at around 0.75 through 2012.

As shown in Table 11.1-3, the bus traffic volume on Avenida Almirante Barroso totaled approximately 610 vehicles per peak hour in 2002. The traffic will increase to 640 and 700 buses per peak hour in 2007 and 2012. Coupled with the rapidly growing motorization in general, the avenue will become the most heavily trafficked and congested road in the study area. By the proposed innovation of bus transportation, the bus traffic on the avenue will be 400 and 360 vehicles per peak hour in 2007 and 2012, a sizable reduction of 240 and 340 vehicles relative to the “without” situation. Moreover, the average driving speed of the other motorized traffic on three lanes each on both sides of the trunk busway is expected to rise by 10%. The trunk bus system will check the deterioration of the traffic condition on Avenida Almirante Barroso, and the reduced commuting time by both bus and private car will benefit the public at large in no uncertain measure.

In 2002, as many as 40 to 50 bus lines plied the intra-city arterial roads such as Avenidas Nazare and Malcher, where the bus traffic was quite heavy, reaching 4,000 to 5,000 vehicles per day. The proposed trunk bus system, with its fleet of large-capacity articulated buses and the peak-hour segregation of priority lanes, will greatly contribute to reducing and redirecting the bus traffic on the roads within the Centro and ultimately serve to ease the chronic traffic congestion of Belem City.

Table 11.1-3 Bus Traffic on Avenida Almirante Barroso

(vehicles/inbound peak hour)

	2002	2007		2012	
		Without Trunk Bus System	With Trunk Bus System	Without Trunk Bus System	With Trunk Bus System
Conventional Bus	610	640	250	700	230
Trunk Bus	-----	-----	150	-----	130
Total	610	640	400	700	360

2) Improved Traffic Safety

The trunk bus system is operated on the existing trunk roads by introducing clear segregation or demarcation between busways (or bus lanes), lanes for other motorized traffic, bikeways and sidewalks. The separation of road space for different types of traffic with different speed will greatly contribute to the traffic safety.

3) Economic Activation

The proposed trunk bus system requires the investment in infrastructure, such as construction or improvement of trunk busways and exclusive trunk bus lanes, trunk bus priority lanes, trunk bus terminals and stops. The development of such social infrastructure will buttress the activation of regional economy.

(4) Benefits to Environmental Conservation

1) Environmental Conservation

The trunk bus system uses the available road space of the existing trunk roads. Because the widening of road space is not required, the proposed system is unlikely to do additional damage to the current situation of the surrounding environment. Nonetheless, it is necessary to take sufficient environmental conservation measures both during and after the construction.

2) Reduced Emission of Nitrogen Oxides (NO_X)

The level of air pollution by NO_X, CO, PM-10 and SO_2 in the study area is currently better than the national environmental standards. However, the situation is sure to deteriorate in the foreseeable future. Without the trunk bus system, the daily emission of NO_X will rise to 12.6 tons in 2007 and 18.5 tons in 2012. With the system, the NO_X emission will be 11.2 and 14.9 tons respectively, lower by 10% and 20% relative to the "without" situation. The introduction of the trunk bus system will be effective to keep the air pollution by NO_X in check.

3) Reduced Emission of Carbon Dioxide (CO_2)

Without the trunk bus system, the daily emission of CO_2 is estimated to reach 1,590 tons in 2007 and 2,850 tons in 2012. With the system, the daily emission will be 1,380 and 2,110 tons, lower by 13 and 26% respectively relative to the "without" situation. The trunk bus system will serve sizably to curtail the CO_2 emission, the major cause of global warming.

4) Reduced Noise Level

The roadside noise level is found to be worse than the national environmental standards in many places of the study area, and the situation is expected to get worse in the future. Without the trunk bus system, the peak-hour noise level along Avenida Almirante Barroso near Sao Braz Terminal is estimated to reach 82.53, 82.03 and 82.06 dBA respectively in 2007, 2012 and 2020. With the system in operation, the noise level will be lowered to 80.62, 80.07 and 79.19 dBA for the same three years. The trunk bus system will serve significantly to keep the roadside noise level in check along heavily trafficked roads.

5) Conservation of Livable Urban Environment

The introduction of the trunk bus system requires appropriate facilities such as trunk busways, exclusive and priority bus lanes, trunk bus terminals and bus stops, with associated improvement on road structure and road space utilization. The development and modernization of such facilities will ensure smooth flows of different vehicular traffic as well as pedestrians. In other words, the proposed innovation of bus transportation will contribute to the improvement of urban transportation as a whole and the conservation of livable urban landscape.

11.2. TRUNK BUS LINES AND SERVICE FREQUENCY

11.2.1. IDENTIFICATION OF BUS LINES

Trunk bus lines are identified to achieve three principal objectives. Firstly, they must meet the present and the future passenger demand. Secondly, they must be routed so as to reduce the bus traffic and thereby alleviate the traffic congestion within the Centro of Belem City. Lastly, they must be routed to disperse the current bus line concentration on a few roads and thereby establish a truly functional bus service network.

The passenger demand assignment on Avenida Almirante Barroso for 2007 and 2012 shows the pattern similar to the current situation. Most passengers will board the bus at one of the terminals in the suburbs and commute to their destinations in the environs of Sao Braz Terminal. Boarding and alighting passengers drop sharply inside the Centro. To accommodate the passenger behaviors and to reduce the bus traffic and congestion within Belem City, the proposed trunk bus operation on the avenue offers two lines per terminal of origin. The first line (01 Bus Line) enters and circles inside the Centro of Belem City and the second line (03 Bus Line) stops at the existing Sao Braz Terminal to return to the terminal of origin.

The passenger demand assignment on Avenida Independencia, which will be completed by 2011, is expected to show the following pattern. Passengers board the bus at one of the terminals of origin and mostly alight along Avenida Pedro Cabral. Boarding and alighting then drop sharply toward and inside the Centro. Given the estimated passenger behaviors, the trunk bus operation on Avenida Independencia offers two lines per terminal of origin, to serve the same purpose of reducing the bus traffic and easing the congestion inside the Centro. The first line (02 Bus Line) travels on Avenida Independencia and enters the Centro to continue its service inside, while the second line (04 Bus Line) stops at Avenida Pedro Cabral to return to the terminal of origin.

On the basis of this assignment, the proposed trunk bus system in 2007 is assumed to operate only on Avenida Almirante Barroso from eight terminals in the suburbs toward the Centro, with a total of 16 bus lines. With the planned completion of Avenida Independencia, a total of 32 bus lines, four per terminal of origin, are assumed to be in operation for meeting the passenger demand in 2012 (Table 11.2-1).

The subsequent detailed demand assignment respectively on 16 and 32 bus lines revealed that two lines, TC03 and TG03, would have only negligible passenger demand in 2007 and that four lines of TC03, TC04, TD03 and TF01 would similarly have few passengers in 2012. Therefore, it is concluded that the trunk bus system operates 14 lines in 2007 and 28 lines in 2012.

11.2.2. OPERATION FREQUENCY BY BUS LINE

The peak-hour operation frequency per trunk bus line is obtainable by dividing the largest route-segment passenger demand of a given line by the articulated bus capacity. Passengers on a given line vary constantly throughout the route from origin to destination, and the largest demand concentrates on certain route segments or between certain bus stops. From the viewpoint of operating efficiency and economy, the bus capacity is set at 120% of the standard capacity. The results of calculation are shown in Table 11.2-1. Salient characteristics of operation frequency are summarized as follows.

1) In 2007, the headway of two trunk bus lines originating from Terminal A is about 8 minutes each. Two feeder bus lines are in operation, each with the headway of about 3

minutes and their passengers transfer to the trunk bus lines at the terminal. In 2012, four trunk bus lines respectively depart the terminal every 10 minutes or so, while four feeder bus lines are available, each with the headway of 3 to 4 minutes.

2) At the busiest Terminal F, two trunk bus lines respectively depart every 3 or 4 minutes in 2007. The headway of two feeder bus lines is about 1.5 minutes respectively. It is estimated that a total of 340 passengers arrive by feeder bus every 4 minutes and that most of these passengers transfer to the trunk bus lines. In 2012, each of the four trunk bus lines departs every 4 to 5 minutes, while four feeder bus lines transport passengers every 1.5 to 3 minutes each.

3) In 2007, all of the proposed 14 trunk bus lines run on Avenida Almirante Barroso to access the Centro. The inbound trunk bus traffic is as heavy as one vehicle every 25 to 30 seconds during peak hours. In 2012, Avenida Independencia will be ready to carry part of the passenger load, and the trunk bus traffic on Avenida Almirante Barroso will decline to one vehicle per 35 to 40 seconds despite the expected increase of the total passenger demand.

4) Regarding the feeder bus lines, it is deemed difficult at this point to determine their exact service routes. Therefore, the operation frequency is tentatively obtained by presuming a number of feeder bus lines available, and dividing the largest peak-hour trunk bus passengers at each terminal by the feeder bus capacity. The feeder bus headway shown in Table 11.2-1 must be understood as such, implying no proposal.

Table 11.2-1 Operating Frequency by Trunk Bus Line

Bus Terminal	Bus Line	Year	No. of Passengers				Capacity (pass./vehicle)		Headway (minutes)			
			Trunk Bus		Feeder Bus				Trunk Bus		Feeder Bus	
			2007	2012	2007	2012	Trunk	Feeder	2007	2012	2007	2012
TA	TA01	2007	1,754	1,438	1,690	1,355	240	84	8.2	10.0	3.0	3.7
	TA02	2012	---	902	---	925	240	84	---	16.0	---	5.4
	TA03	2007	1,700	1,459	2,077	1,762	240	84	8.5	9.9	2.4	2.9
	TA04	2012	---	1,575	---	2,149	240	84	---	9.1	---	2.3
TB	TB01	2007	1,520	1,309	1,520	1,320	240	84	9.5	11.0	3.3	3.8
	TB02	2012	---	429	---	429	240	84	---	33.6	---	11.7
	TB03	2007	1,385	1,465	1,202	1,211	240	84	10.4	9.8	4.2	4.2
	TB04	2012	---	520	---	520	240	84	---	27.7	---	9.7
TC	TC01	2007	1,750	793	1,732	783	240	84	8.2	18.2	2.9	6.4
	TC02	2012	---	263	---	263	240	84	---	54.8	---	19.2
	TC03	2007	0	0	0	0	240	84	---	---	---	---
	TC04	2012	---	0	---	120	240	84	---	---	---	42.0
TD	TD01	2007	3,725	4,537	3,325	4,537	240	84	3.9	3.2	1.5	1.1
	TD02	2012	---	523	---	523	240	84	---	27.5	---	9.6
	TD03	2007	1,134	0	853	0	240	84	12.7	---	5.9	---
	TD04	2012	---	197	---	197	240	84	---	73.1	---	25.6
TE	TE01	2007	2,274	2,318	1,634	1,587	240	84	6.3	6.2	3.1	3.2
	TE02	2012	---	1,226	---	1,226	240	84	---	11.7	---	4.1
	TE03	2007	483	971	343	687	240	84	29.8	14.8	14.7	7.3
	TE04	2012	---	2,220	---	1,376	240	84	---	6.5	---	3.7
TF	TF01	2007	3,973	0	3,070	3,704	240	84	3.6	---	1.6	1.4
	TF02	2012	---	2,969	---	1,397	240	84	---	4.9	---	3.6
	TF03	2007	3,487	3,788	3,487	3,788	240	84	4.1	3.8	1.4	1.3
	TF04	2012	---	3,092	---	2,086	240	84	---	4.7	---	2.4
TG	TG01	2007	3,095	2,403	982	290	240	84	4.7	6.0	5.1	17.4
	TG02	2012	---	1,058	---	136	240	84	---	13.6	---	37.1
	TG03	2007	0	1,561	0	348	240	84	---	9.2	---	14.5
	TG04	2012	---	300	---	218	240	84	---	48.0	---	23.1
TH	TH01	2007	3,633	2,745	676	665	240	84	4.0	5.2	7.5	7.6
	TH02	2012	---	2,261	---	362	240	84	---	6.4	---	13.9
	TH03	2007	3,083	1,068	1,268	330	240	84	4.7	13.5	4.0	15.3
	TH04	2012	---	1,625	---	1,150	240	84	---	8.9	---	4.4

11.3. PROCUREMENT OF NEW BUSES

11.3.1. FLEET REQUIREMENTS FOR TRUNK BUS SYSTEM

The trunk bus system requires articulated buses (double-body unit with capacity of 200 passengers) and feeder buses (capacity of 70 passengers). The fleet size is obtainable basically from the largest peak-hour passengers per line of the proposed 28 trunk bus lines and the trunk bus capacity, with some adjustments by the respective line length, the operating speed and the turn-around frequency. Regarding the feeder bus lines, it is not possible at this point to determine the exact routes for their services. The number of bus fleet required is tentatively calculated from the largest peak-hour passengers per trunk bus terminal and the feeder bus capacity, assuming that 2 to 4 lines will be available at each trunk bus terminal. Therefore, the number of fleets suggested for feeder bus lines must be understood as such, implying no proposal. It will be necessary to decide the efficient feeder bus routes and recalculate the necessary number of fleets, before introducing the trunk bus system. The following assumptions are made to estimate the necessary trunk and feeder bus fleets.

1) The value of the largest bus passengers used to calculate the trunk bus fleet is taken from the assignment results per trunk bus line.
2) The value of the largest bus passengers used to calculate the feeder bus fleet is taken from the assignment results on passengers boarding at each trunk bus terminal.
3) The route length is the distance of each trunk bus line from origin to destination, while the feeder bus route is assumed to be in the range of 2.0 to 2.5 km one way.

Table 11.3-1 shows the results of calculation for each trunk bus line. The conclusion from the calculation can be summarized as follows.

1) A total of 150 articulated buses with capacity of 200 passengers will be necessary for 2007 when the trunk bus system starts its operation. The fleet will have to be increased to 213 articulated buses by 2012.
2) 53 feeder buses with capacity of 70 passengers will be necessary in 2007, and the fleet will have to be increased to 76 buses by 2012.
3) Each trunk bus terminal will require a fleet of 20 to 25 articulated buses in 2007 and 25 to 30 in 2012.

Table 11.3-1 Fleet Requirements for Trunk Bus System

Name of Bus Terminal	Bus Line	Operation Year	Bus Line Length Trunk Bus (km)	Bus Line Length Feeder Bus (km)	Operati Speed Trunk Bus (Km/h)	Operati Speed Feeder Bus (Km/h)	Bus Sycle Time Trunk Bus (Time/h)	Bus Sycle Time Feeder (Time/h)	No.of Passenger Trunk Bus 2007 (Person)	No.of Passenger Trunk Bus 2012 (Person)	No.of Passenger Feeder Bus 2007 (Person)	No.of Passenger Feeder Bus 2012 (Person)	Bus Fleet Transport Capacity Trunk Bu (Pas./v)	Bus Fleet Transport Capacity Feeder Bus (Pas./v)	No. of Trunk Bus in 2007 (Vehicle)	No. of Trunk Bus in 2012 (Vehicle)	No. of Feeder Bus in 2007 (Vehicle)	No. of Feeder Bus in 2012 (Vehicle)	Bus Operation Frequency Trunk Bus 2007 (Minute)	Bus Operation Frequency Trunk Bus 2012 (Minute)	Bus Operation Frequency Feeder Bus 2007 (Minute)
TA	TA01	2007	28	2.5	32.5	25	1.2	10.0	1754	1,438	1,690	1,355	240	84	13	10	4	3	8.2	10.0	3.0
	TA02	2012	26	2.5	32.5	25	1.3	10.0	0	902	0	925	240	84	0	6	0	2	―――――	16.0	―――――
	TA03	2007	23	2.5	32.5	25	1.4	10.0	1700	1,459	2,077	1,762	240	84	10	9	5	4	8.5	9.9	2.4
	TA04	2012	23.3	2.5	32.5	25	1.4	10.0	0	1,575	0	2,149	240	84	0	9	0	5	―――――	9.1	―――――
	Sub-Total														**23**	**34**	**9**	**15**			
TB	TB01	2007	18.1	2	32.5	25	1.8	12.5	1520	1,309	1,520	1,320	240	84	7	6	3	3	9.5	11.0	3.3
	TB02	2012	16	2	32.5	25	2.0	12.5	0	429	0	429	240	84	0	2	0	1	―――――	33.6	―――――
	TB03	2007	13.1	2	32.5	25	2.5	12.5	1385	1,465	1,202	1,211	240	84	5	5	2	2	10.4	9.8	4.2
	TB04	2012	13.3	2	32.5	25	2.4	12.5	0	520	0	520	240	84	0	2	0	1	―――――	27.7	―――――
	Sub-Total														**12**	**15**	**5**	**7**			
TC	TC01	2007	13.3	2	32.5	25	2.4	12.5	1750	793	1,732	783	240	84	6	3	3	1	8.2	18.2	2.9
	TC02	2012	14.9	2	32.5	25	2.2	12.5	0	263	0	263	240	84	0	1	0	1	―――――	54.8	―――――
	TC03	2007	8.4	2	32.5	25	3.9	12.5	0	0	0	0	240	84	0	0	0	0	―――――	―――――	―――――
	TC04	2012	12.2	2	32.5	25	2.7	12.5	0	0	0	120	240	84	0	0	0	0	―――――	―――――	―――――
	Sub-Total														**6**	**4**	**3**	**2**			
TD	TD01	2007	16.1	2	32.5	25	2.0	12.5	3725	4,537	3,325	4,537	240	84	15	19	6	9	3.9	3.2	1.5
	TD02	2012	18.1	2	32.5	25	1.8	12.5	0	523	0	523	240	84	0	2	0	1	―――――	27.5	―――――
	TD03	2007	11.1	2	32.5	25	2.9	12.5	1134	0	853	0	240	84	3	0	2	0	12.7	―――――	5.9
	TD04	2012	15.4	2	32.5	25	2.1	12.5	0	197	0	197	240	84	0	1	0	0	―――――	73.1	―――――
	Sub-Total														**19**	**22**	**8**	**10**			
TE	TE01	2007	15.1	2.5	32.5	25	2.2	10.0	2274	2,318	1,634	1,587	240	84	9	9	4	4	6.3	6.2	3.1
	TE02	2012	18.7	2.5	32.5	25	1.7	10.0	0	1,226	0	1,226	240	84	0	6	0	3	―――――	11.7	―――――
	TE03	2007	10.2	2.5	32.5	25	3.2	10.0	483	971	343	687	240	84	1	3	1	2	29.8	14.8	14.7
	TE04	2012	17.1	2.5	32.5	25	1.9		0	2,220	0	1,376	240	84	0	10	0	0	―――――	6.5	―――――
	Sub-Total														**10**	**27**	**5**	**8**			
TF	TF01	2007	20.6	2.5	32.5	25	1.6	10.0	3973	0	3,070	3,704	240	84	21	0	7	9	3.6	―――――	1.6
	TF02	2012	25.9	2.5	32.5	25	1.3	10.0	0	2,969	0	1,397	240	84	0	20	0	3	―――――	4.9	―――――
	TF03	2007	16.6	2.5	32.5	25	2.0	10.0	3487	3,788	3,487	3,788	240	84	15	16	8	9	4.1	3.8	1.4
	TF04	2012	23.2	2.5	32.5	25	1.4	10.0	0	3,092	0	2,086	240	84	0	18	0	5	―――――	4.7	―――――
	Sub-Total														**36**	**54**	**16**	**26**			
TG	TG01	2007	17.6	2.5	32.5	25	1.8	10.0	3095	2,403	982	290	240	84	14	11	2	1	4.7	6.0	5.1
	TG02	2012	16.6	2.5	32.5	25	2.0	10.0	0	1,058	0	136	240	84	0	5	0	0	―――――	13.6	―――――
	TG03	2007	12.7	2.5	32.5	25	2.6	10.0	0	1,561	0	348	240	84	0	5	0	1	―――――	9.2	―――――
	TG04	2012	12.9	2.5	32.5	25	2.5	10.0	0	300	0	218	240	84	0	1	0	1	―――――	48.0	―――――
	Sub-Total														**14**	**21**	**2**	**2**			
TH	TH01	2007	20.5	2.5	32.5	25	1.6	10.0	3633	2,745	676	665	240	84	19	14	2	2	4.0	5.2	7.5
	TH02	2012	18.4	2.5	32.5	25	1.8	10.0	0	2,261	0	362	240	84	0	11	0	1	―――――	6.4	―――――
	TH03	2007	15.5	2.5	32.5	25	2.1	10.0	3083	1,068	1,268	330	240	84	12	4	3	1	4.7	13.5	4.0
	TH04	2012	15.7	2.5	32.5	25	2.1	10.0	0	1,625	0	1,150	240	84	0	7	0	3	―――――	8.9	―――――
	Sub-Total														**31**	**36**	**5**	**6**			
Total															**150**	**213**	**53**	**76**			

11.3.2. PROCUREMENT SCHEDULE

(1) Current Status of Bus Fleet in Service

As of 2002, 29 private companies operate 165 bus lines in the study area with a combined fleet of 1,864 buses. As shown in Table 11.3-2, the average age of the fleet is relatively young at 5.5 years and only a few have been in service for 10 years or more. As shown in Figure 11.3-1, the age distribution of the fleet is gently bell-shaped, peaking at the buses of 5 to 6 years in service that together account for more than 40% of the total. The age distribution of the fleet will flatten out, as the efficiency of bus operation and management is improved in the future with the scheduled annual purchase of new vehicles.

Table 11.3-2 Age Distribution of Present Bus Fleet

Years in Service	No. of Buses	Cumulative Total	Share (%)
1	86	86	4.6
2	94	180	5.0
3	111	291	6.0
4	250	541	13.4
5	427	968	22.9
6	408	1,376	21.9
7	279	1,655	15.0
8	145	1,800	7.8
9	29	1,829	1.6
10	35	1,864	1.9
11	0		
12	0		
Total	1,864		100.0

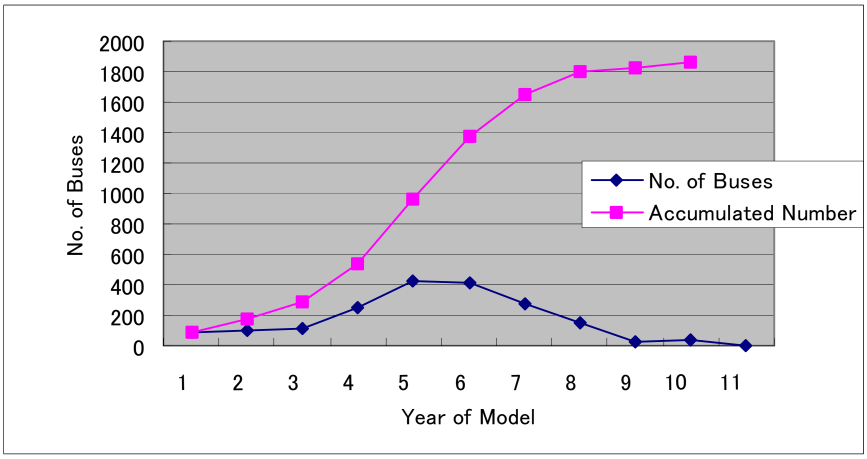


Figure 11.3-1 Age Distribution of Present Bus Fleet

(2) Schedule of Bus Fleet Procurement

The proposed trunk bus system will replace 61 of the present 165 bus lines. The future fleet requirements of three bus types on these 61 bus lines are shown in Table 11.3-3.

Table 11.3-3 Fleet Requirements by Bus Type

	Conventional Bus		Trunk Bus		Feeder Bus	
	2002	2007	2007	2012	2007	2012
Large Bus	394	446	0	0	0	0
Articulated Bus	0	0	150	213	0	0
Medium Bus (70 passgrs.)	0	0	0	0	53	76

To plan the fleet replacement and expansion, it is assumed that the service life of a bus will be 10 years and that the fleet will have a flattened age distribution. The details of the fleet procurement schedule are described in Chapter 20. Salient points of the proposed schedule are summarized as follows.

1) In 2002, 394 conventional buses are in operation on 61 bus lines. 197 buses, or about 50%, will be out of service in five years through 2007. The fleet of conventional buses will increase to 446 single-body vehicles by 2007 when the trunk bus system is expected to start its operation to replace them. Accordingly, it is necessary in the coming five years to procure 249 conventional buses (446-394+197=249).

2) In 2007, the trunk bus system will require a fleet of 150 articulated buses to start its operation. Considering the availability of serviceable conventional buses, however, it will be economical to use them and reduce the cost of purchasing articulated buses in the beginning.

3) In 2007, 446 conventional buses will be operating and available. 300 of them are equivalent in passenger capacity to 150 double-body articulated buses. In the beginning, the trunk bus system will operate paired convoys of 300 conventional buses. In addition, 53 conventional buses will be operated as feeder buses.

4) The remaining 93 conventional buses will be transferred to the other conventional bus lines.

11.4. VEHICULAR REQUIREMENTS OF TRUNK BUS SYSTEM

11.4.1. Structural Requirement

The trunk bus system operates a fleet of articulated double-body buses. Figure 11.4-1 shows the side, front, back and inside views of an articulated bus. Major specifications are as follows.

1) Articulation of two bodies

2) Standard capacity of about 200 passengers

3) Because the peak-hour passengers are expected to increase to 120%, or 240 passengers, of the capacity, the body structure must be strong enough to carry the heavy load.

4) Four doors, or two per body, are available for passenger boarding and alighting.

5) Passengers board the bus by the front door and alight from the back door of each body.

6) The doors are provided on the right side of the bodies.

7) The standard seating arrangement is four seats per row, or two seats on both sides of the center aisle. In order to meet the peak-hour demand, however, the number of seats will be reduced with widened center aisle, as shown in Figure 11.4-2.

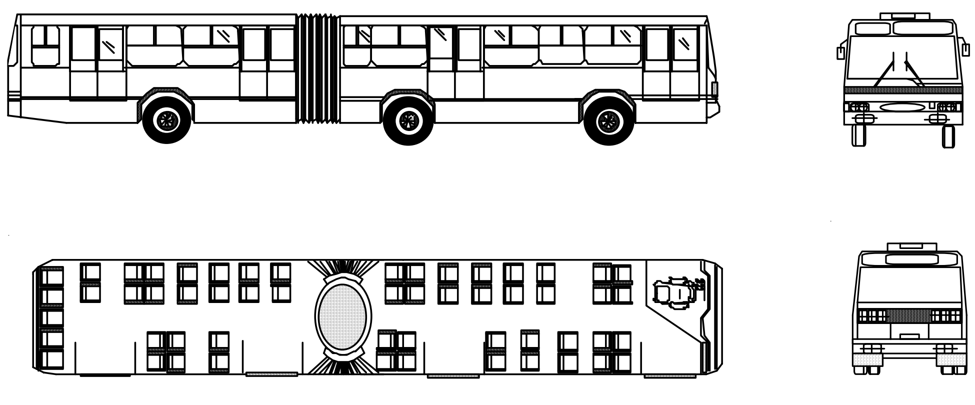


Figure 11.4-1 Standard Cross-Section Views of Four-Door Articulated Bus

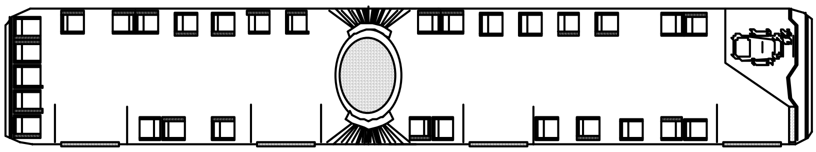


Figure 11.4-2 Modified Seating Arrangement

11.4.2. ENVIRONMENTAL REQUIREMENT

As of 2002, the level of air pollution by various pollutants in the study area is lower than the national standard regulations. However, the volume of emission is sure to increase apace with the expected growth of motorized traffic in the foreseeable future. To counteract the global warming, an increasing number of governments in the world are trying to develop and disseminate low-emission cars. European countries are now considering the raising of the emission standard from the current EURO-2 to EURO-3 or EURO-4. Japan has been promoting the increased use of buses fueled by compressed natural gas (CNG) and developing new low-emission hybrid buses.

The growing global trend is the use of CNG-fueled buses, although various attempts are underway to develop new low-emission engines. CNG engines are mechanically the same as diesel engines but use compressed natural gas instead of diesel oil. The emission of nitrogen oxides (NO_x) by CNG-fueled engines is 60 to 80% lower than diesel-fueled engines. The emission of hydrogen monoxide (HC) and carbon monoxide (CO) is also lower by 80% and 70% respectively.

Therefore, it is advisable to switch gradually from the current diesel-fueled buses to the CNG-fueled ones in the study area. It must be pointed out, however, that the CNG-fueled buses have a few disadvantages. Firstly, they are more expensive, costing 20 to 30% more than diesel-fueled buses. Secondly, they have shorter driving distance of 200 to 250km per one filling. Thirdly, there are a very limited number of CNG filling stations in Brazil. These problems will have to be overcome as early as possible. In Japan, the Environmental Protection Agency of the national government has established a financial facility to subsidize private bus companies that are willing to change their fleets from diesel- to CNG-fueled buses. Regarding the study area, it is proposed to establish a CNG filling station at each trunk bus terminal. (Proposed trunk bus lines range from 40 to 50 kilometers in length. This means that trunk buses have to refill after 4 to 5 round trips.)

11.5. FARE SYSTEM

11.5.1. FARE COLLECTION

The bus fare is currently paid in either cash or coupon ticket at the time of boarding. Passengers board the bus by the back door and pay the fare to the conductor and move to the front door to get off the bus. There is a small table and a turnstile in front of the conductor's post near the back door. Passengers have to pay the fare anew when they transfer from one line to another.

The fare system proposed for the trunk bus operation is integrated at eight terminals between trunk bus lines and between trunk and feeder bus lines. Transfers between trunk and conventional bus lines are not integrated: passengers have to pay the fare anew when they transfer from one to the other. Because all trunk bus lines are in the range of 15 to 20km in total length, the fare will be uniformly fixed.

It is estimated that two trunk bus lines operate with the respective headway of 5 to 8 minutes from each of the eight terminals during peak hours. This implies that the trunk bus traffic on Rodovia Augusto Montenegro and Rodovia BR-316 is one bus every minute, and that the traffic gets heavier at one bus every 30 seconds on Avenida Almirante Barroso where two roads merge. With the current fare system, a passenger needs 2.0 to 2.5 seconds to board the bus. At bus stops where 10 passengers are waiting, their boarding takes 20 to 25 seconds. In order to operate trunk buses every 30 seconds, it is crucial to reduce the time needed for boarding. Accordingly, the trunk bus operation will introduce the following fare collection system.

1) Electronic card system will be gradually introduced, however conductor will be still necessary.
2) Passengers board the bus by the front door and get off by the back door.
3) Several types of cards are used in various cities of the world, such as prepaid cards, smart cards, contactless IC cards, credit cards and magnetic cards used per ride. Since the proposed trunk bus system is expected to start its operation in 2007, there is enough time to examine the available options and make the final decision. The future socio-economic prospects of the study area, opinions and attitudes of bus passengers and the management capability of bus companies will have to be closely analyzed to select the most suitable card type.

As for electronic fare media, recently, the electronic media offers even more convenience to current and potential transit users. At present, there are various types of programs developed in oversea, but even many of those examples are still in trial of pilot phases. In the USA, European countries and Japan, development of several multipurpose programs has begun, but in-service applications are of limited scope to date. Therefore, the outline of current electronic fare media is shown in Appendix-B in this section, which includes basic institutional approach, card technology and issues of the system, and also present conditions of fare collection system in the USA.

11.5.2. SALE OF TICKETS, COUPONS AND TERM PASSES

Tickets, coupons and term passes may be sold at shops, kiosks, bus terminals, or shopping centers. Passengers must buy tickets or coupons before boarding a trunk bus and before entering an integrated bus terminal. This will substantially shorten the time needed for passenger boarding. To avoid the expected initial confusion, it might be necessary to allow the payment in cash for the first few months.

11.5.3. RESTRUCTURING OF MANPOWER

The proposed trunk bus system introduces a fleet of larger articulated buses and the more efficient bus operation. Therefore, it is likely to necessitate the sizable restructuring of the currently employed drivers, conductors and other personnel. During the initial stage of the trunk bus operation, it might be necessary to ease the inevitable pain of restructuring by letting the redundant workers tend the bus terminal that operates and maintains the bus terminal.

11.6. TRUNK BUS FLOW CONDITIONS

11.6.1. GENERAL

The maximum bus traffic on Avenida Almirante Barroso recorded approximately 600 vehicles per peak hour in 2002. The traffic will increase to 640 and 700 buses per peak hour in 2007 and 2012 respectively. Coupled with the rapidly growing motorization in general, Avenida Almirante Barroso will become the most heavily trafficked and congested road in the region. By the proposed innovation of bus transportation, the total bus traffic (trunk and conventional buses) on Avenida Almirante Barroso will be 400 and 360 vehicles per peak hour in 2007 and 2012 respectively, a sizable reduction of 240 (in 2007) and 340 vehicles (in 2012) relative to the Without case.

Since the trunk bus flow rate on the trunk busway on Avenida Almirante Barroso and on the priority lane in the Centro area is very heavy as above-mentioned, it is necessary to verify the bus flow conditions on the trunk bus system, taking into account dwelling time at bus stops and behavior at signalized intersections. Therefore, on Av. Almirante Barroso and Av. Gov. Jose Malcher in the trunk bus system, the bus operation performance is simulated on a computer by means of a simulation model. By the model, it is possible to predict the effect of operation performance, as expressed in terms of measures of effectiveness, which include average vehicle speed, vehicle stops, delays, etc.

The TSIS models, which involve software supported by the Federal Highway Administration in U.S.A. (FHWA), was used in the Study. The TSIS is an integrated software system that consists of NETSIM and others. NETSIM is a microscopic stochastic simulation model of urban traffic.

In this section, the future traffic conditions on the trunk busway on Av. Almirante Barroso and on the priority lane on Av. Gov. Jose Malcher are validated with the TSIS model. The necessity of the trunk bus system in 2007 and 2012 is identified.

11.6.2. PROCEDURE OF ANALYSIS

(1) Procedure

In order to simulate traffic characteristics on Av. Almirante Barroso and Av. Gov. Jose Malcher, the road segments on Av. Almirante Barroso between Entroncamento and Travares Bastos, and between Travessa Castelo Branco and Av. Generalissimo Deodoro were selected as study roads. Figure 11.6-1 shows the study location analyzed by traffic simulation model. Both segments are typical of the trunk busway and the trunk bus priority lane, as well as heavy in traffic. The procedure of analysis is as follows:

1) To collect present traffic data
   - Bus flow volume
   - Private vehicle traffic volume for straight, left and right-turn movement
2) To collect road inventory data
   - Number of lanes
   - Location of bus stops
   - Number of bus bays
   - Traffic signals: locations, cycle length, and off-set time
3) To set parameters for simulation model

- Bus fleet size
- Dwelling time at bus stops
- Operation headway
- Driver characteristics

4) To calibrate the present traffic conditions
5) To simulate traffic conditions for buses and private vehicles in the Without case and to disclose the limit of the current bus system.
6) To simulate traffic conditions for trunk buses and private vehicles in the With case and to predict traffic conditions on mixed traffic lanes, the trunk busway and the trunk bus priority lane with signalized intersections.

Figure 11.6-2 summarizes the estimation flowchart by traffic simulation model for traffic conditions on the trunk busway on Av. Almirante Barroso and the priority lane on Av. Gov. Jose Malcher.

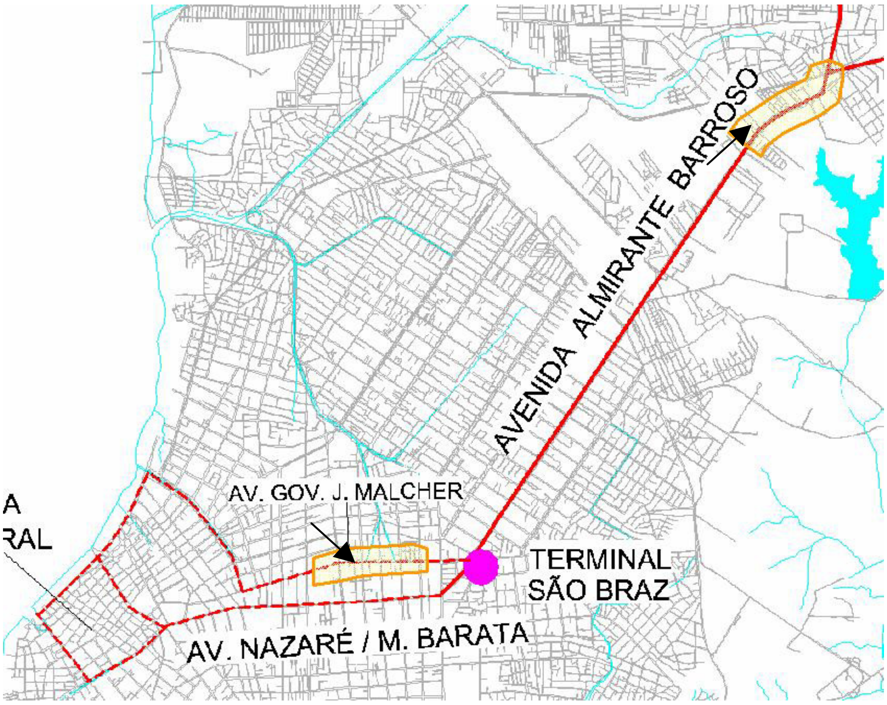


Figure 11.6-1 Study Location analyzed by Traffic Simulation Model

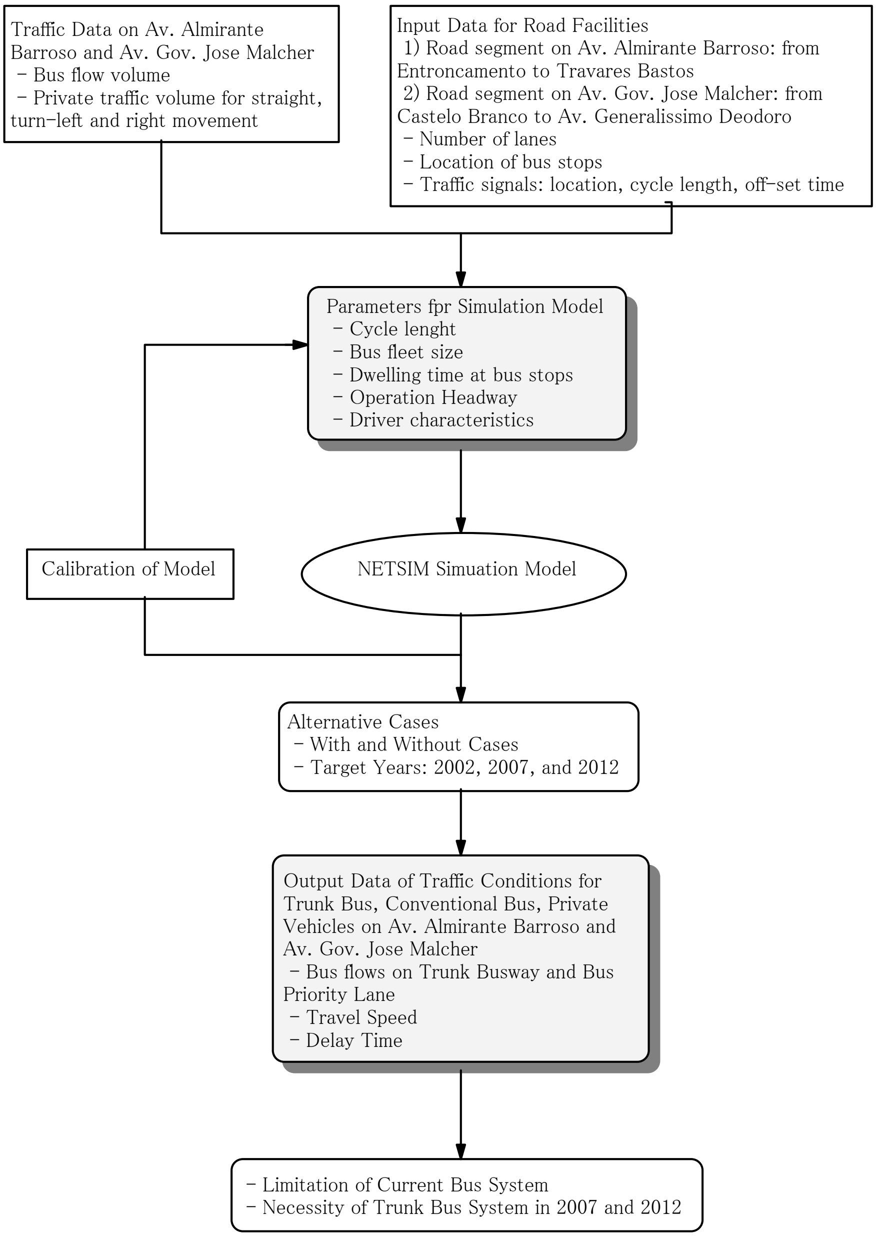


Figure 11.6-2 Estimation Flowchart of Traffic Simulation

(2) Output Data

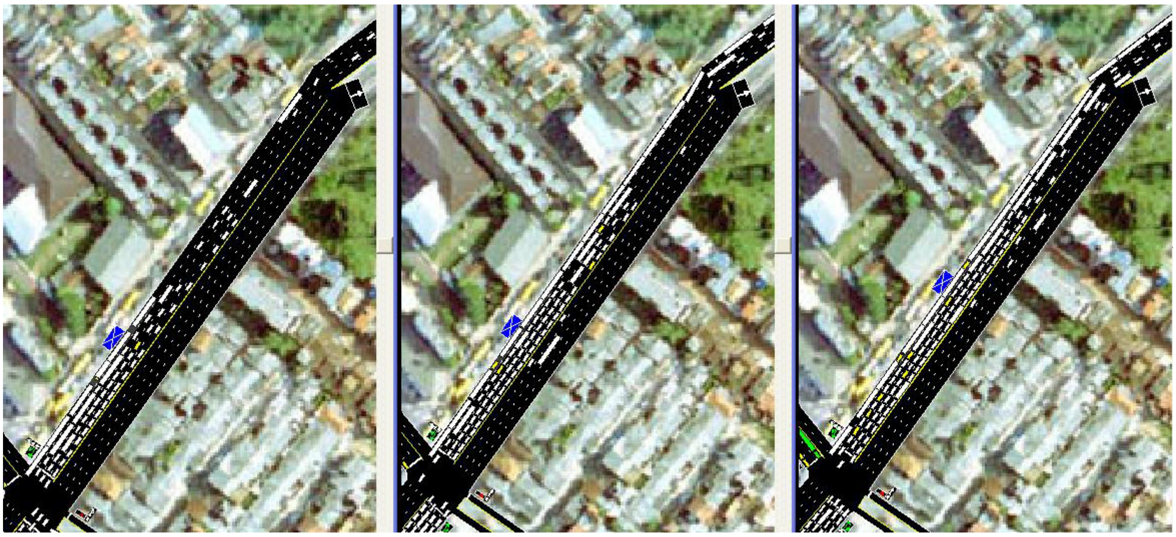
The system operation performance is expressed in terms of measures of effectiveness, which include bus flows, service frequency, average vehicle speed, maximum delay time and queue length at intersections derived from the simulation model.

11.6.3. BUS FLOW CONDITIONS ON AV. ALMIRANTE BARROSO

Traffic flow conditions on segregated busway and mixed traffic lanes in terms of traffic volume, average travel speed, maximum queue length and delay time, are analyzed on Av. Almirante Barroso. The proposed trunk bus system is evaluated by comparing those indices in both Without and With cases. In the Without case, conventional bus and private vehicles run on mixed traffic lanes. On the other hand, the trunk bus runs on the segregated busway, and conventional buses and private vehicles run on mixed lanes in the With case.

(1) Traffic Flows

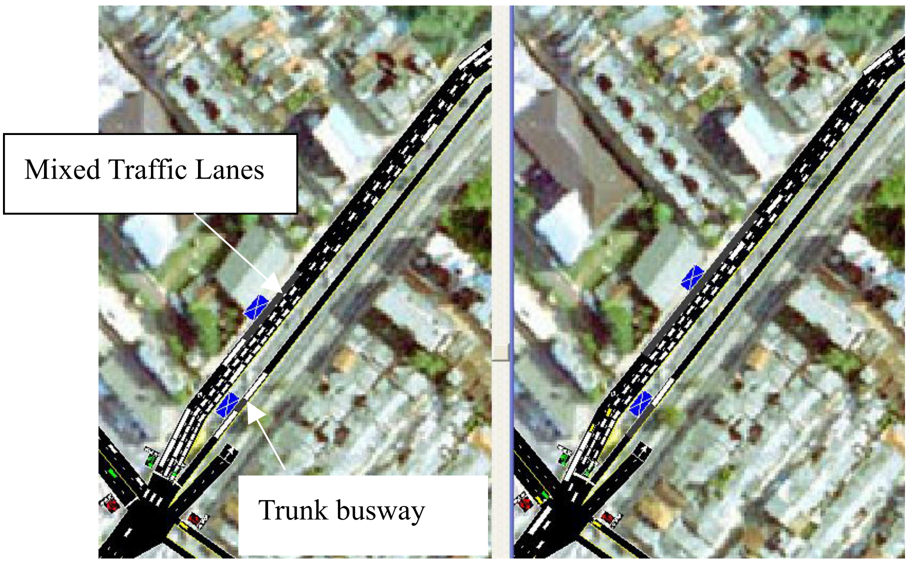
Figure 11.6-3 shows traffic flows on Av. Almirante Barroso in 2003, 2007 and 2012 in the Without case, and gives a bird's eye view picture of a road segment of Av. Almirante Barroso. The buses are illustrated with a large rectangle and private vehicles show as small rectangles. Peak hour bus volume in 2003 is approximately 430 veh/h. The 2007 and 2012 bus volumes in the peak hour are approximately 620 and 720 veh/h, respectively. As can be seen, bus density on the road becomes higher according to those years and the buses occupy two lanes on the road.



Traffic Volume in 2003 In 2007 In 2012

Figure 11.6-3 Traffic Volume on Av. Almirante Barroso by A Bird's Eye View Picture in 2003, 2007 and 2012 in Without Cases

Figure 11.6-4 also shows the traffic volume by a bird's eye view picture in 2007 and 2012 in the With case, in which the trunk busway is modeled as a separated road.



Traffic Volume in 2007 Traffic Volume in 2012

Figure 11.6-4 Traffic Volume on Av. Almirante Barroso by A Bird's Eye View Picture in With Cases

Peak hour bus volume in 2007 is approximately 150 veh/h for the trunk bus and 260veh/h for the conventional bus. The 2012 trunk and conventional bus volumes in the peak hour are approximately 130 and 260 veh/h, respectively. As can be seen, the trunk buses are smoothly operated on the segregated busway in both 2007 and 2012, while traffic of private vehicles and conventional buses on mixed traffic lanes is somewhat heavy. The detailed analysis of traffic conditions, such as travel speed, maximum queue length and delay time, is shown in following sections.

(2) Travel Speed

Figure 11.6-5 shows the average travel speed by trunk busway and mixed traffic lanes on Av. Almirante Barroso. The travel (bus operation) speed includes waiting time, alighting and boarding time at bus stops, and waiting time at signalized intersections. In 2007, the average travel speed on mixed lanes in the With case is higher (17km/h) than that in the Without case (13km/h). The trunk bus speed is higher than that of conventional buses. Its figure is approximately 22km/h, in contrast to 17km/h of conventional buses. In 2012, the trunk bus speed is similar (23km/h) to that in 2007. The travel speed on the mixed lanes in the With case (16km/h) is higher than that in the Without case (14km/h). This indicates that the travel speeds of trunk buses, conventional buses and private vehicles are increasing on the trunk bus system, i.e., traffic conditions are also improved.

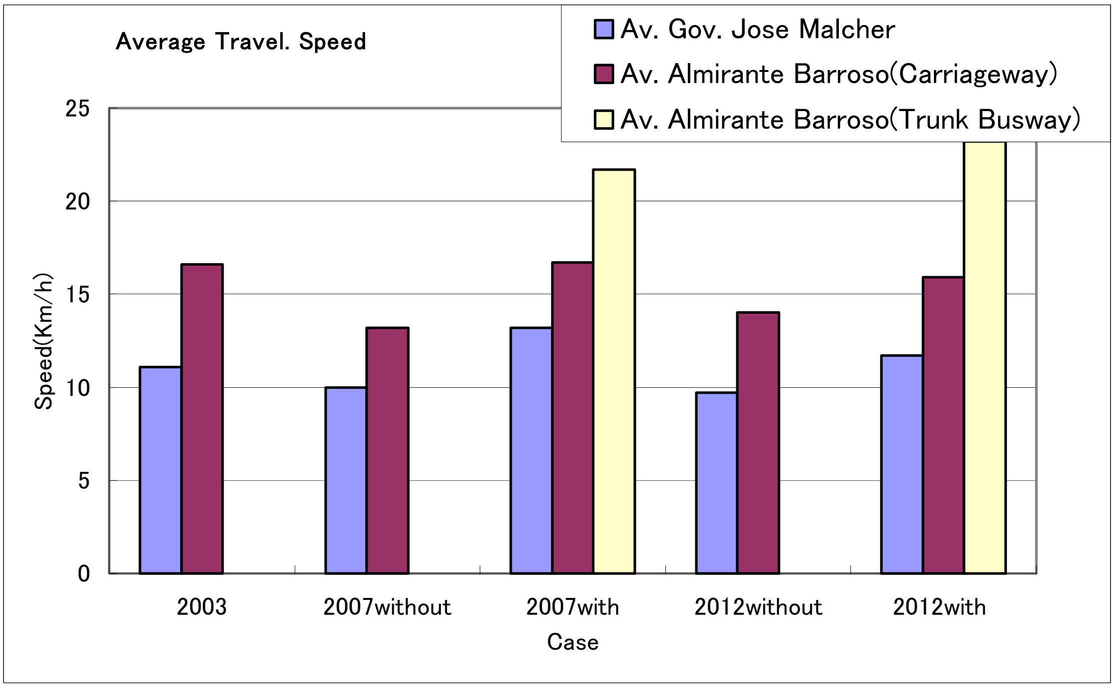


Figure 11.6-5 Average Travel Speed

(3) Maximum Queue Length

Figure 11.6-6 shows maximum queue length in terms of vehicle numbers at signalized intersections by trunk busway and mixed traffic lanes on Av. Almirante Barroso. In the Without case in 2007 and 2012, the queue lengths are longer than that in 2003. Those figures are approximately 26 and 29 vehicles respectively at intersections on the mixed traffic lanes, in contrast to 18 vehicles in 2003. In the With case, the queue lengths in 2007 and 2012 are similar lengths to the present value. Its figures are in the range of 18 to 22 vehicles on the mixed traffic lanes. The trunk buses on the trunk busway take few queue lengths with 2 vehicles in both 2007 and 2012.

The queue length at intersections is an indicator of traffic congestion on a road. According to the analysis, the queue length on the mixed traffic lanes in 2012 to the present value rises by 1.6 times in the Without case, while in the trunk bus system (With case) the figure rises only 1.2 times.

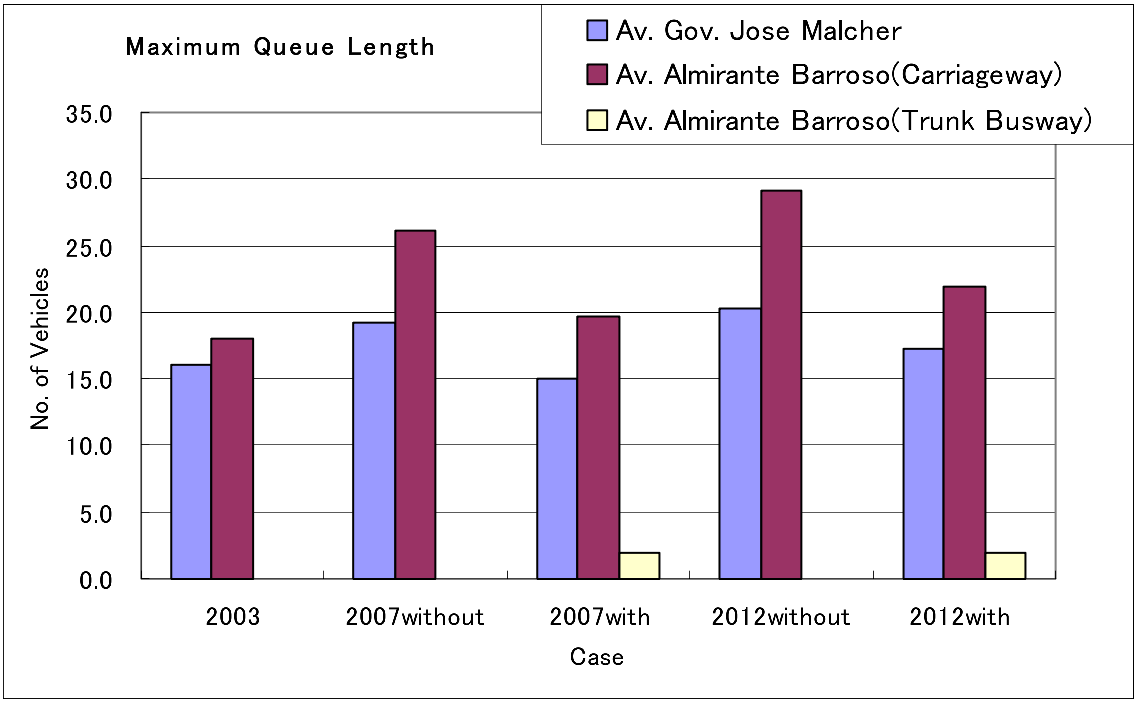


Figure 11.6-6 Maximum Queue Length

(4) Delay Time

Figure 11.6-7 shows delay time within the segment on Av. Almirante Barroso, which is the difference between the actual travel time and the travel time if constantly moving at the free flow speed. The delay time not only includes increased travel time from reduced speed but also time added due to traffic control. In the Without case, in 2007 and 2012, the delay time is longer than that in 2003. Those figures on the mixed traffic lanes are approximately 460 and 430 vehicle-minutes respectively, in contrast to 220 vehicle-minutes in 2003. In the With case, the delay time on the mixed traffic lanes in 2007 and 2012 is slightly increased, compared to the present value. Its figures are near 330 to 380 vehicle-minutes respectively. The delay time of the trunk buses on the trunk busway in 2007 and 2012 is 10 and 7 vehicle-minutes, respectively.

The delay time also indicates traffic congestion degree, as well as the queue length. The delay time on the mixed traffic lanes in 2012 to the present value rises by 1.9 times in the Without case, while in the trunk bus system (With case) the figure only rises by 1.7 times. From the indicator of the delay time it is obvious that the trunk bus system also improves traffic conditions.

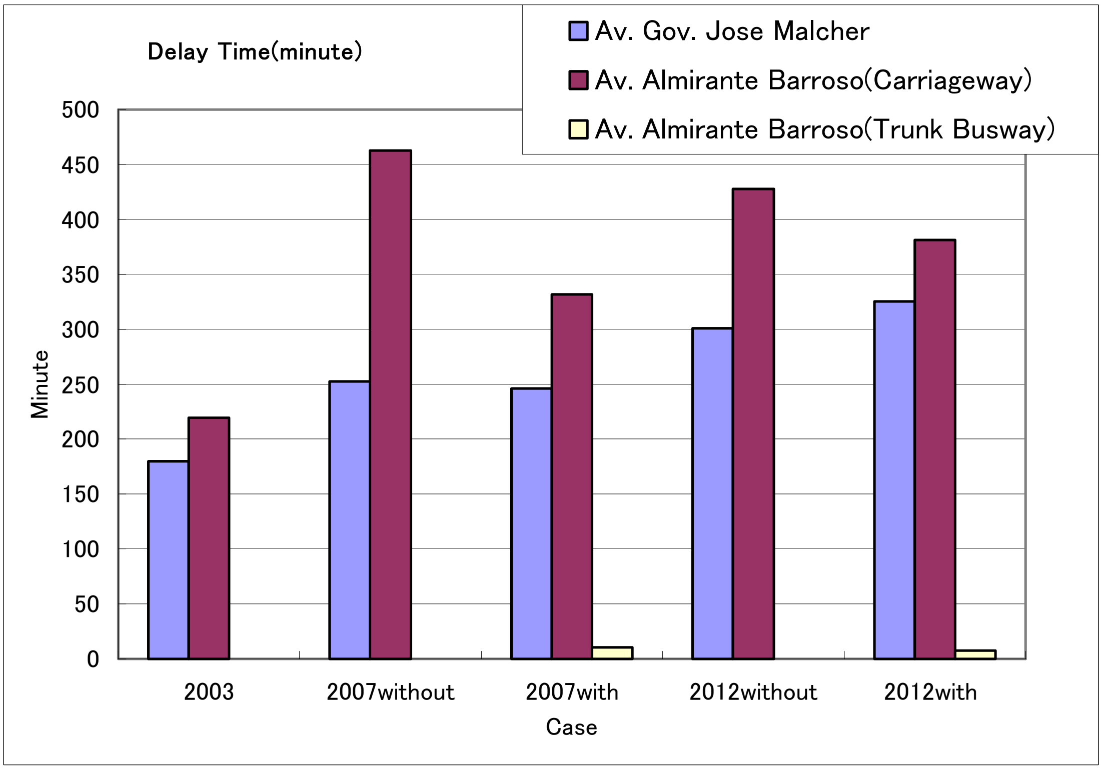


Figure 11.6-7 Delay Time

(5) Forecast of Maximum Bus Flow Rates on Av. Almirante Barroso

Figure 11.6-8 shows the relationship between bus flow rate and operation frequency on Av. Almirante Barroso between Entroncamento and Av. Tavares Bastos in which bus flow rate is simulated on the assumption that only bus frequency gradually increases under the present traffic volume in 2003. As can be seen, the higher the frequencies are, the heavier the bus flow rates are and then, the bus flow rates gradually decrease after the frequencies reach some high values. This means since the bus traffic congests on the road in proportion to higher bus frequencies, buses cannot smoothly flow and bus flow rates decrease on the road. Since in the model, each vehicle's behavior can be simulated in a manner reflecting real world processes, no matter how high the service frequency is, bus flow rates decrease due to unstable flow conditions.

As can be seen in Figure 11.6-8, the highest number of bus flow rates on this segment is approximately 550 in peak hour. The future demand bus traffic volumes in 2007 and 2012 are over 600 veh/h. Under the current bus system, it will be difficult to operate bus service frequency equivalent to the future demand volume. According to the analysis with the model, the present bus volume on this segment on Av. Almirante Barroso nearly reaches critical density. The current bus system is close to its limits.

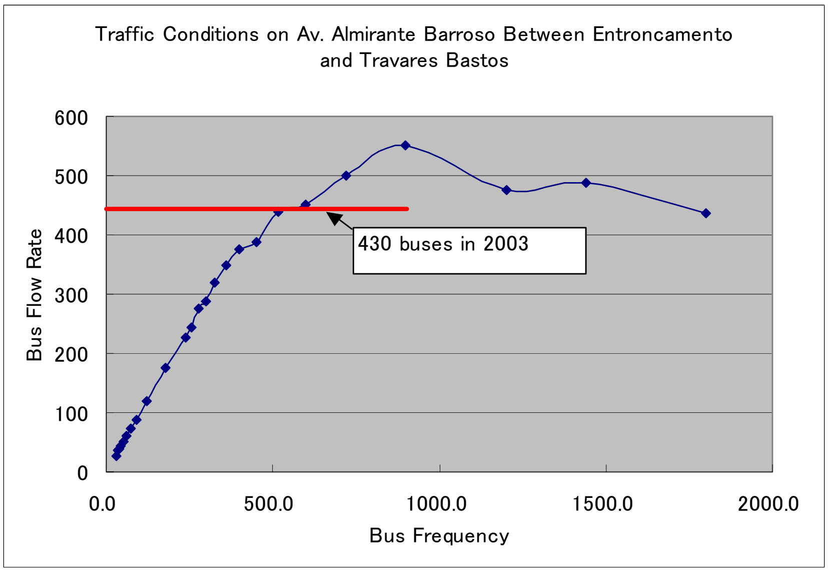


Figure 11.6-8 Relationship between Bus Flow Rate and Frequency

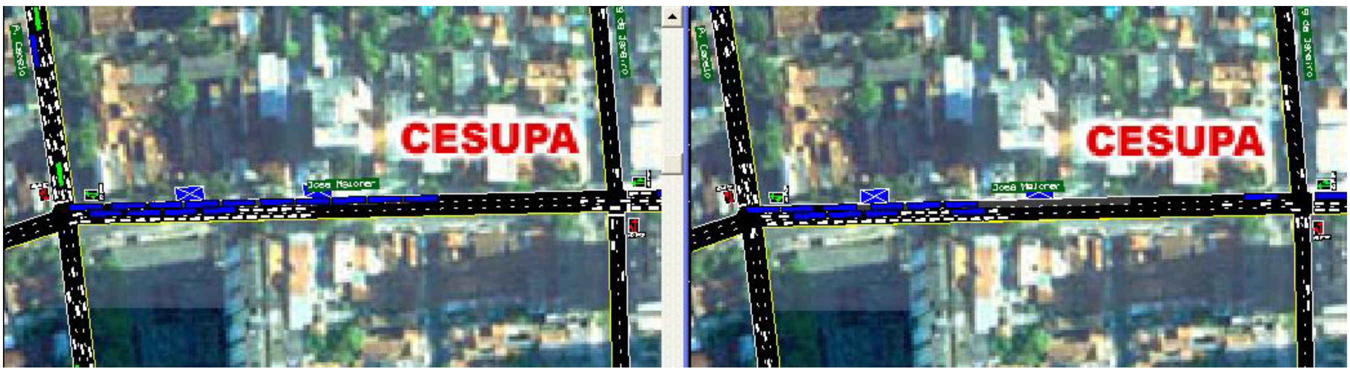
11.6.4. Bus Flow Conditions on Av. Gov. Jose Malcher

On Av. Gov. Jose Malcher, a trunk bus priority lane is planned in the trunk bus system, in which trunk buses are operated giving priority to the mixed traffic lanes with private vehicles. The travel conditions on the trunk bus priority lane are severer than those on the trunk busway which segregates the trunk buses from private vehicles. This is because private vehicles turn into the priority lane due to right-turn movement and hinder operation of the trunk bus. The trunk bus flow conditions are also analyzed in the same manner as those on the trunk busway on Av. Almirante Barroso and compared to each other.

Figure 11.6-9 shows traffic flows on Av. Gov. Jose Malcher in 2003, 2007 and 2012 in the Without case in which the trunk and conventional buses are illustrated as a large blue rectangle and private vehicles are shown as white small rectangles. Figure 11.6-10 and Figure 11.6-11 show the difference between traffic flows in the Without and With cases in 2007 and 2012, respectively.

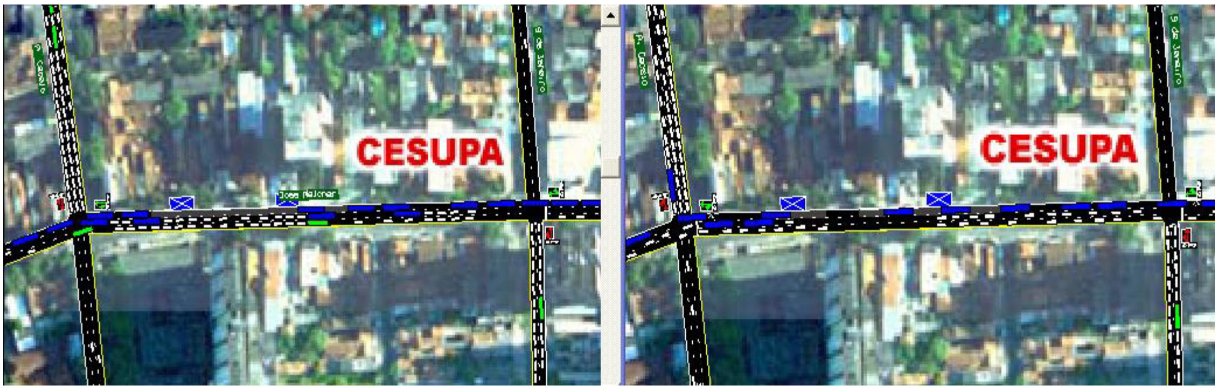
As can be seen in Figure 11.6-9, peak hour bus volume in 2003 is approximately 390 veh/h. The 2007 and 2012 bus volumes in the peak hour in the Without case are approximately 470 and 480 veh/h, respectively. Bus and private vehicle density on the road becomes higher according to those years and buses occupy two lanes on the road. As can be seen in Figure 11.6-10 and Figure 11.6-11, in the With case, peak hour bus volume in 2007 is approximately 90veh/h for trunk buses and 300 veh/h for conventional buses. The 2012 trunk and conventional bus volumes in the peak hour are approximately 80 and 280 veh/h, respectively. In the With case, in the future, both trunk and conventional bus volumes reduce to approximately 80% of the Without case. Therefore, the traffic density in the With case—especially bus density—is somewhat lower than that in the Without case.

Figure 11.6-9 Traffic Volume on Av. Gov. Jose Malcher by a Bird's Eye View Picture in 2003, 2007 and 2012 in Without Cases



Without Case With Case

Figure 11.6-10 Traffic Volume on Av. Gov. Jose Malcher in 2007 in Without and With Cases



Without Case With Case

Figure 11.6-11 Traffic Volume on Av. Gov. Jose Malcher in 2012 in Without and With Cases

The travel speeds of trunk buses on the bus priority lane in 2007 and 2012 in the With case are slightly higher than those in the Without case as shown in Figure 11.6-5. On the priority lane, the future bus operation speeds in the With case are approximately 12-13km/h in spite of being somewhat improved, in contrast to 23km/h on the trunk busway on Av. Almirante Barroso.

The maximum queue length and delay time on Av. Gov. Jose Malcher are smaller in d than those on Av. Almirante Barroso. This is because traffic volume on Av. Gov. Jose Malcher is lower than that on Av. Almirante Barroso.

In the With case, the maximum queue length in 2012 of both trunk and conventional buses on the priority lanes is reduced to approximately 85% that of the Without case (see Figure 11.6-6). On the other hand, the future delay time is also reduced to approximately 92% that the Without case (see Figure 11.6-7).

The construction of the trunk bus system will raise the bus operation speed and reduce the maximum queue length and the delay time by decreasing total bus volumes on the priority lane.

11.7. BUS OPERATION TECHNOLOGY

11.7.1. PUBLIC TRANSPORT PRIORITY SYSTEM (PTPS)

(1) Introduction

The trunk bus system, which basically operates on the segregated busway, serves increasing public transport demand together with securing the punctuality and increasing the convenience of public transport. Although the segregated busway has its own traffic space, it does not have priority operation space at intersections, unlike the rail transit system. Therefore, the trunk bus will be obliged to follow traffic signals at intersections. The installation of bus priority traffic signals at intersections on trunk busways aims to maximize the merit of the trunk busway and to realize the coexistence between trunk bus operation and ordinary road traffic.

The signal priority has been a promising method to improve bus, or in general, bus operations and service quality. Traditional traffic signal system have had limited capabilities, resulting in simplistic bus priority strategies, such as extending the green phase. Recent advancements in the field of Intelligent Transportation System (ITS) have created new capabilities to support transit priority in traffic signal systems. These advancements cover a wide range of features including detection, communications, control hardware, optimization algorithms, and simulation modeling.

The expected benefits of bus signal priority (BSP) are as follows.

- Improved mobility and transportation and transit efficiency through the optimization of traffic control signals.
- Increased operational and regulatory efficiencies for system users and public agencies.
- Reduced environmental impacts by reducing emissions from vehicular use.
- Improved traveler information and data collection for more effective policy planning and operational management.
- Improved safety and reduction in number of collisions.
- Improved travel times and schedule adherence for the bus fleet.

(2) BSP Strategies

Basic priority concepts and the strategies that define and differentiate these concepts are outlines below.

1) Control Strategies

The four (4) kinds of control strategies for awarding BSP are:

- Real-time: Rely on constantly updated information to make decisions regarding priority. A real-time signal control model is more flexible to changing conditions, hence is generally more effective.
- Fixed-time: Fixed-time control applies a signal control plan based on the average conditions of an area. Fixed-time control does not receive constantly updated information; the best control scheme is applied to the area regardless of actual conditions.
- Schedule-based: Priority is awarded based on the bus schedule. If the bus is running late then it receives priority through intersections. Schedule-based control is more

effective at reducing bus travel times. Since schedule-based control does not need information of bus locations it requires less communication equipment, which makes it more cost effective.

- Headway-based: Priority is awarded based on the headway between buses. Buses avoid bunching up with other buses in this control strategy. Headway-based control is more effective at reducing wait times.

2) Priority Concepts

The two (2) types of basic bus priority concepts are:

- Active priority: Each bus is detected on approach to an intersection and the signals are then changed. Active system can be a combination of real or fixed-time control strategies, and schedule or headway-based control strategies. Active concepts are more effective and widely used.
- Passive priority: Traffic control devices are adjusted to suit the bus schedule along the route in general using a combination of fixed-time and schedule-based control strategies. Passive priority does have the benefit of being lower in cost, however it has limited potential to improve bus operations.

Table 11.7-1 Summary of BSP Strategies

Control Strategies	
Real-time	Priority changes based on constantly updated information
Fixed-time	Applies a fixed plan to make decisions regarding priority
Schedule-based	Priority awarded based on the bus schedule
Headway-based	Priority awarded based on the headway between buses
Priority Concepts	
Active priority	Signal is adjusted for each bus on detection at intersection approach
Passive priority	Signals are adjusted to suit the bus schedule along the route

Source: Effectiveness of Bus Signal Priority, Final Report, January 2002, National Center for Transit Research (NCTR), Univ. of South Florida, Report No. NCTR-416-04

3) BSP Systems

a) Bus Information and Priority System (BIPS) offers bus priority without the large increase in delays to other traffic. BIPS is an active real-time system that can utilize different methods of detection. It considers the entire bus priority system as a network that contains interacting buses and intersections. BIPS utilizes five (5) modules to exchange information and determine what kind of priority should be given to each bus. The modules used are:

- *Projection on Route Module* receives bus-positioning messages (wave based, dead reckoning and beacon system may be utilized) and then returns information.
- *Traffic Flow Estimator Module* receives traffic volume information and then returns congestion information and estimates the degree of congestion and travel time.

- *Travel Time Prediction Module* receives information about the status of signals later on in the route of the bus and determines an estimated time for travel through the route.
- *Priority Processing Module* communicates with the travel time prediction modules to get information on various data.
- *Monitor and Control Module* starts the other modules and communicates between them.

b) Microprocessor Optimized Vehicle Actuation (MOVA) is a bus priority system that utilizes a signal control system to analyze lane data and control signal timing. MOVA is an active real-time system. MOVA employs a variety of bus priority techniques depending on the situation of each priority request. If the bus is arriving when the light is already green, the green signal can be extended to allow enough time for the bus to travel through the intersection under normal conditions. If the bus is arriving when its signal is in a red phase, the other phases can be skipped or truncated, depending on the situation.

c) Split Cycle Offset Optimization Technique (SCOOT), an active urban traffic control system, provides real-time optimization. Bus priority is given via green extension, green recall, and resynchronization. Various detection methods can be used with the system such as transponders and AVL.

(3) Equipments of Bus Signal Priority

1) Bus priority traffic signal with public transportation priority systems (PTPS)

Typical bus priority traffic signal with public transportation priority system (PTPS) shows Figure 11.7-1. By this method, the vehicles are identified by obtaining the correlation value between the images of the vehicle that pass through a surveillance point (which are fed continuously by a television camera installed above the busway) in relation to a previously created reference template image that represents the characteristics of a specific vehicle such as bus on busway. The traffic signal lights are regulated by extending the green light, shortening the red light, or quickly changing the green light in the opposite direction, according to the time in which such bus arrives at the intersection.

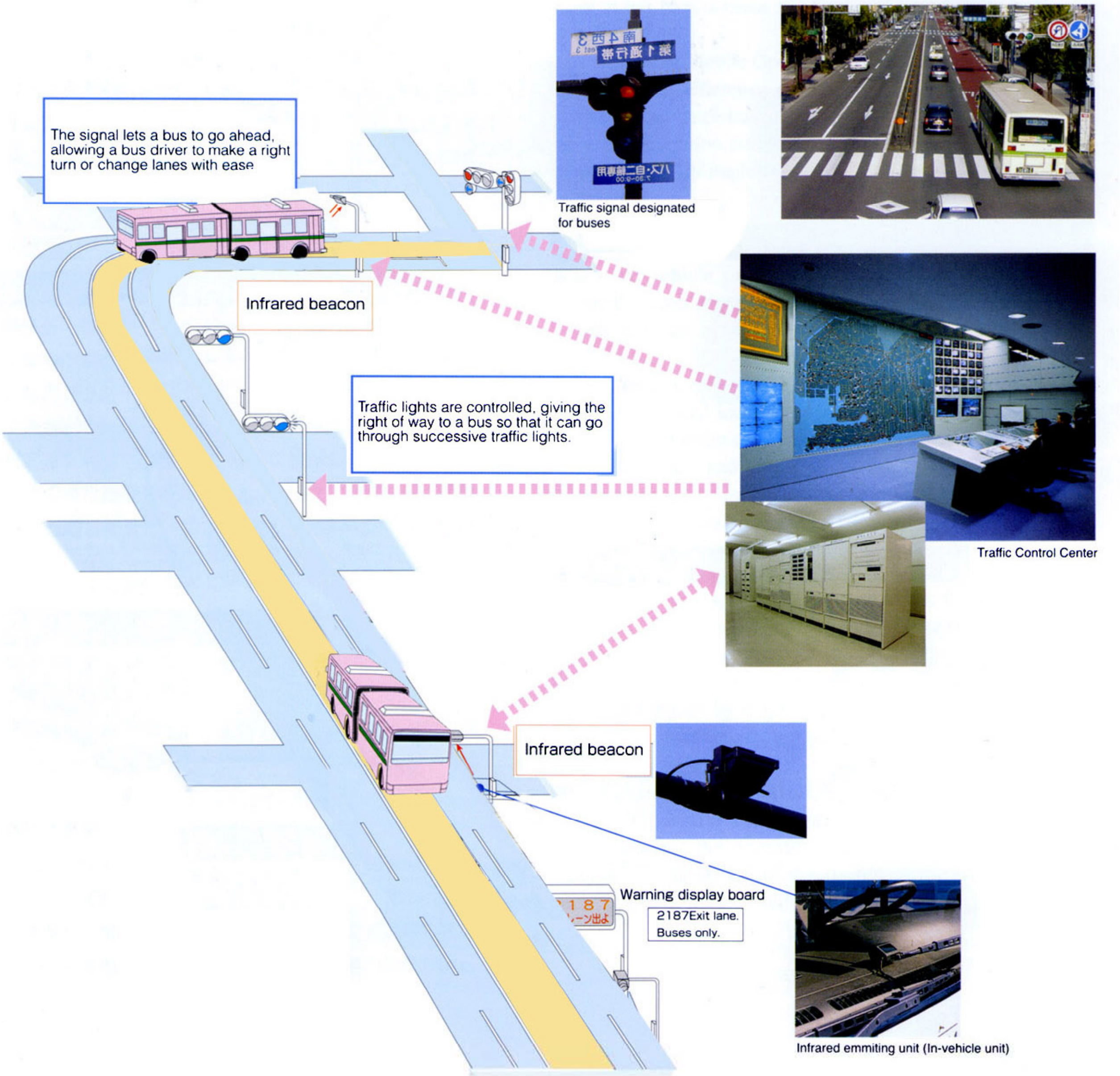


Figure 11.7-1 Image of Bus Priority Traffic Signal with Public Transportation Priority Systems

2) *Bus priority traffic signal utilizing a loop vehicle detector*

When a bus passes over a loop vehicle detector, which is a loop coil buried underneath road pavement, the bus is detected and this information is relayed to the next traffic signal or to the Traffic Control Center.

This vehicle detector allows traffic signals or the Traffic Control Center to track the bus, clearing its way and shortening waiting time at intersections as much possible.

3) *Bus priority traffic signal utilizing a method for identifying specific vehicles by matching TV image patterns*

In order to secure the punctuality of bus operation along the busway, it is necessary to regulate the signal lights by extending the green light, shortening the red light, or quickly changing the green light in the opposite direction, according to the time in which such bus arrives at the intersection.

To execute this type of signal control, a signal is emitted so that the traffic signal light can properly identify the operating bus along the busway.

By this method, the vehicles are identified by obtaining the correlation value between the images of the vehicle that pass through a surveillance point (which are fed continuously by a television camera installed above the busway) in relation to a previously created reference template image that represents the characteristics of a specific vehicle such as a bus on busway.

(4) Bus Priority Traffic Signal proposed in the Trunk Bus System

There are 250 traffic signals installed in Belem and controlled by CTBel. Out of this number, 200 signals are synchronized, divided into 6 transport corridors in the CBD. There is no area traffic control within all the CBD because of the limited capacity of the computer currently used for traffic control. The remaining (50 traffic signals), which are mainly located in the suburban area, are controlled individually.

It is important to introduce bus priority traffic signals for the effective operation of the busway. The introduction of bus priority traffic signals on the trunk busway in the suburban area is more effective, especially at integrated bus terminals along the principal arterial roads such as BR-316. However, in the CBD the introduction of bus priority signals should be carefully considered. This is since the trunk bus operation headway will be forecast at less than 20-30 seconds in both directions, the roads with busways might cause traffic congestion.

Considering the current system of traffic control in Belem, it is advisable to introduce the conventional system such as bus priority traffic signal utilizing a loop vehicle detector, as described above, for the short-term; and then introduce a highly developed technology such as bus priority traffic signal with public transportation priority systems (PTPS).

Sixteen (16) proposed bus priority traffic signals are planned as follows. The locations of those traffic signals are shown in Figure 11.7-2.

- 7 traffic signals at the integrated bus terminals in exclusive of Icoaraci Bus Terminal
- 8 traffic signals in Centro area
- 1 traffic signal at Entroncamento roundabout intersection

At the integrated bus terminals, the bus priority traffic signals are installed at entrance and exit of buses to smooth left-turn moving buses from trunk busway or exclusive trunk bus lane. On the other hand, in Centro area the bus priority signal prioritizes the left-turn trunk and conventional buses. At Entroncamento roundabout intersection where the trunk busway is changed to an ordinary traffic lane with mixed traffic, the trunk and conventional buses with left-turn movement are prioritized to private vehicles.

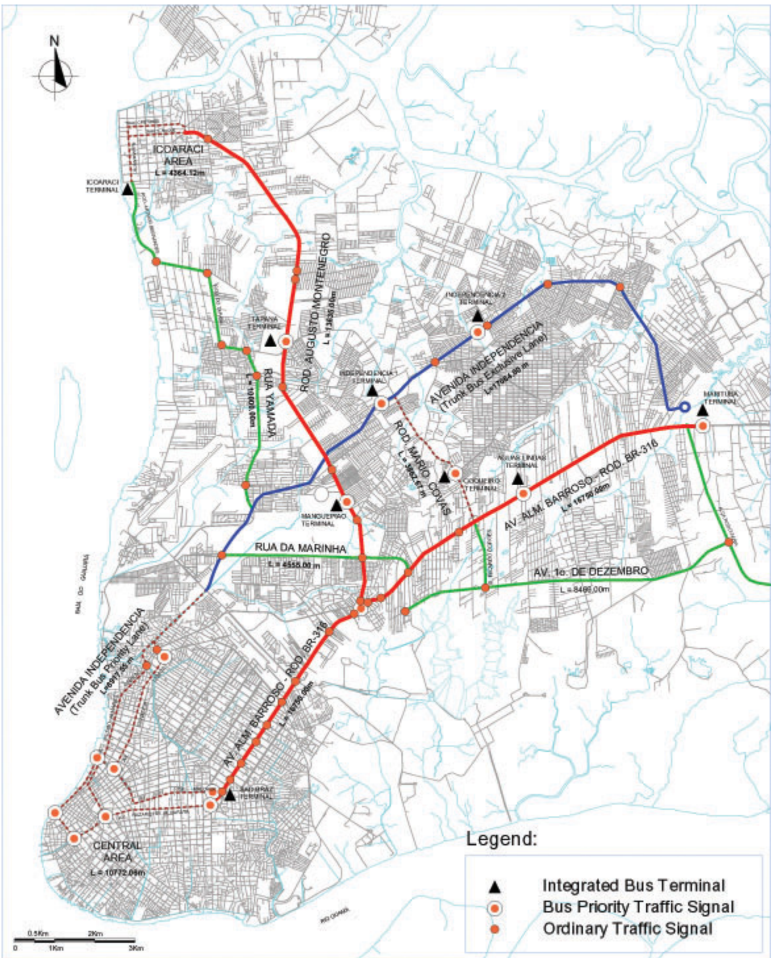


Figure 11.7-2 Locations of Bus Priority Traffic Signal

11.7.2. AUTOMATED VEHICLE LOCATION SYSTEM (AVL SYSTEM)

Bus transportation agencies are turning to advanced technologies to improve service, increase safety, and attract ridership. Specially, automatic vehicle monitoring (AVM) systems are being developed on bus transport to achieve operational system benefits. Although AVM systems were deployed in the 1970s and 1980s, only recently have transit agencies embraced the concept. The core technology, the automatic vehicle location (AVL) system, offers detailed status information previously absent from the bus operations, customer support, maintenance, and service planning areas.

The AVL system tracks vehicle movement. This capability, integrated with other functions, enables transit agencies to provide new and improved services, such as reduced emergency response time, real-time bus status information, automated passenger counting information, and improved mobile communications.

In future, it will be necessary to introduce the AVL technology to improve bus operation services. However, in this study the AVL technology proposes as a next challenge. Therefore, the outlines of AVL system and bus navigation service by GPS in Japan are shown in Appendix-B in this section. From among bus navigation system in Japan, the system of Tokyu Bus Corporation, which operates buses within the Tokyo metropolitan area is introduced here. The company serves bus operation with bus navigation service by using GPS technology.