PUBLIC TRANSPORT POLICIES IN EUROPE: IMPLEMENTING BUS RAPID TRANSIT SYSTEMS IN MAJOR EUROPEAN CITIES

Cristian Canales
Civil Engineering School of Barcelona. Technical University of Catalonia
Miquel Estrada
Leif Thorson
Francesc Robuste
Centre for Innovation in Transport. Technical University of Catalonia

1. INTRODUCTION

Population growth exerts considerable pressure on infrastructure and natural resources in urban regions. One of the most obvious in daily life is the transportation system, both in terms of how it impacts the environment and the congestion typically experienced in most cities. The relationship between the transportation system, urban form, trip demand, and energy use is paramount in addressing the challenges presented by urban growth. This may be attributed to the considerable economic inefficiency and environmental degradation associated with excessive private vehicle travel based on current technology.

The challenge for urban planners and decision makers is to identify effective strategies for dealing with resistance to travel by public transport. One important factor is ensuring that the urban public transport system is a viable travel alternative. In particular, the system must get people from where they are to where they need to go in a reasonable amount of time.

The decision about which means of transport will serve a particular corridor demand in a metropolitan area would take into account the generalized cost of users and the capital cost and land implications associated to the administrations role. In this way, the creation or enlargement of a public transport network would consider the accessibility (related to the stop spacing and network coverage), the capacity and the expected travel time (related to the right of way, traffic signal coordination, layout, maximum speed and average dwell time) and the necessary capital cost to provide the service. It is important to notice that there is a significant trade-off between the network accessibility and the travel time associated to a public transport service.

Thus, railways and LRT (Light Rail Transit) systems show the highest commercial speed and capacity with huge investments. On the other hand, bus systems are known to be the services that offer the largest accessibility and flexibility in city centres. They do not cause high infrastructure costs because bus routes generally run along the same platform of private cars. However, their low commercial speeds, the lack of passenger time-headway reliability, bus bunching at stops and traffic congestion are key daily problems to be overcome in order to fulfil the requirements of the users and to assure the system profitability for operators.

In this way, traditional bus systems have recently evolved to a new concept of network designs in order to increase their efficiency. These revolutionary bus systems, known as BRT (Bus Rapid Transit), have taken advantage of some characteristics of rail systems in order to determine an optimal balance between accessibility and rapid services in a cost-efficient way. As it is pointed out in Levinson *et al*. (2003), BRT systems provide faster operating speeds, a rise of passengers' reliability and quality of service. In order to meet these goals, BRT are based on some upgrades of system performance such as exclusive bus lanes, busways, signal preference or coordination, traffic management improvements and new technologies for increasing the boarding/alighting time rates.

Bus Rapid Transit systems have been implemented in several metropolitan areas of the world in order to provide high quality transport services between CBD and their outlying towns. The concept of BRT was created in dense populated cities of South America in the early eighties, where budget constraints did not allow constructing heavy rail lines in the demand corridors. From this time to now, other metropolitan areas in Europe, North America and Australia have promoted this reengineered mode as an efficient solution to travel demand requirements and have proposed policies to develop these systems. Generally, both BRT and Light Rail Transit (LRT) lines are able to carry 20,000pax/h and their associated commercial speed is estimated to be 25 km/h (up to 80km/h in special implementations such as highways or guided systems). However, the unit construction cost per distance in BRT lines is less than five times the associated value in LRT lines.

Moreover, the concept of BRT has been applied to particular bus lines that go through dense populated quarters of the same city (trunk lines). Although these lines do not meet the commercial speeds of interurban BRT lines throughout a metropolitan area, they have become as a real efficient alternative to railways in Europe due to its low-cost and a proper travel time of the whole transport chain (access, waiting, on-board, transfer and destination time).

The main objective of this paper is to analyse different existing policies to promote BRT systems all over the world in order to assess their efficiency, especially in Europe. In addition, initiatives of BRT system in Spanish scenario will be summarized as well as some studies modelling their implementation. This breakdown will consequently lead to an evaluation of the need for upgrades and improvements to provide a more attractive BRT network configuration according to the parameters of service quality and efficiency.

2. BRT POLICIES AND IMPLEMENTATION IN SOUTH AMERICA, NORTH AMERICA AND AUSTRALIA

The South American cities are characterized for having high trips demand levels in public transport, continuous urban areas of great extension, limited road supply and traffic congestion. Additionally, the main differential characteristic is the restriction of economic resources to develop systems of massive public transportation by railways (high investment). In this sense, the systems of BRT have been implemented in urban corridors of high demand. The strategies adopted in South America are quite similar, in them extensive measures of priority are offered to surface public transport means. The main characteristics of the design of the network are based on the physical separation of the road infrastructure, besides other notable actions in measures such as restrictions of the cars. They are difficult experiences to find in Australian and North American cities.

Curitiba - Brasil
It is a city that stands out among other cities on a worldwide level for their implementation of bus systems; in 1972 it transformed its main street into a pedestrian walkway. The integrated network of Transportation by bus (RIT) has five different corridors, with four types of services: express, feeders, within neighbourhoods, and direct, with 20 terminals of integration. The express service (direct) uses two-articulated buses of 25 m in length (270 passengers), that carry in rush hour 22.000 passengers in one direction (a similar number to that of the subway). It uses special stops called "tube stations" (70 passengers) which allow for a faster passenger boarding of passengers with anticipated payment. Right now, this system transports 2.1 million passengers per day.

Porto Alegre - Brasil
In 1976 the city established recommendations for the implementation of different corridors for the bus (radial and transversal ways that connect the city). The system is made of 14 private and 1 public lines, including five corridors for the buses. The corridors are connected to transfer stations, that are emphasized (recognized) for their efficient coordination in the boarding/alighting zone and their adequate designs (multimodal terminals). The stops are located in centre of the avenues and the access of the passengers is facilitated by special stoplights. Currently, the system transports 1 million passengers per day.

Bogota - Colombia
The Transmillenium system counts on 6 trunk corridors in way segregated with 2 types of service, the first one being express (specific stops in the route) and the other one being standard (stops all throughout the route). The corridors are segregated, with double exclusive busway, permitting progress in route and stop (feeder services circulate for a mixed way of traffic). The stops are located at the center of the corridor, designed for the embarkment on both sides, and it uses smart cards for the payment method. It uses the three doors for boarding.

Quito – Ecuador

The electric trolleybus in Quito is part of a system of guided buses in segregated way operated by express and feeder services. The way is situated in the central zone of the platform and is divided into 2 sections: one of exclusive use of trolebus (11.2 km) and another exclusive way utilized by conventional buses (4.9 km). In the crossings, the traffic signals are programmed to give priority to the trolleybuses. The stops are a combination of islands or medium physical, with elevated platforms, anticipated payment, and wider doors to facilitate the boarding process.

Table 1. List of operational characteristics of BRT in South America

City	Year first opened	Popu-lation (Millions)	Length (km)	Costs (US$-€Millions)	Cost per km (US$Millions/km)	Average station spacing (m)	Weekday bus riders	AM PEAK HOUR BUSES	AM PEAK HOUR RIDERS	Speeds (km/h) ALL STOP	Travel time reduccion (%)
Curitiba	1973	1.6	60.0	N/A	N/A	430	340,000	40	11,000	19	N/A
Porto Alegre	1978	1.3	4.4	N/A	N/A	300	290,000	326	26,100	18 - 23	29%
Porto Alegre	1978	1.3	3.6	N/A	N/A	300	235,000	304	17,500	19 - 23	29%
Bogotá	2000	5.0	38.0	184.0	4.8	640	800,000	N/A	27,000	21	32%
Quito	1996	1.5	16.0	57.6	3.6	500	170,000	N/A	16,000	18 - 20	N/A

Source: Canales (2006) and Levinson *et al* (2003).

The North American and Australians cities have their own specific characteristics and are very different from their European and South American counterparts, due to their urban structures. The lines of BRT have a significant extension and are used to cover the demands of access to the great city from residential neighbourhoods, crossing over areas of low population density. Besides, one must add that due to the great territorial expansion of these cities, the distances of the trips are a lot greater that in the case of the Europeans.

Ottawa - Canada

The Transitway system has 26 km of lanes used exclusively by the buses, including bus lanes in the main streets of the downtown area of the city and the periphery (highway), with 5 stations of transfer (4 Park&ride). They present a good design, location of the stops and transfer stations. The location of stations is based on the proximity of potential trip attractors and generators zones. The truck service #95 and 97 circulate along the Trasitway and they lend service 22 hours per day.

Brisbane – Australia

The BRT system unites the CBD with the southern suburbs by a highway of six lanes, of which two lanes are exclusively for buses (one per direction). The design of the stations permits detentions and progress without any objection or queue. The stations have attractive designs and are open 24 hours a day; they include 2 platforms for boarding and alighting. Half of the bus lines in Brisbane use part of these exclusive buslanes.

Adelaida – Australia

The O-Bahn is the system which uses a rail bus to connect the central area of the city with the northeast suburbs (zone of congested highways). It uses 18 bus lines and has two access stations at each end of the route (interchangeable). Its adaptability is emphasized by the buses being able to leave their boundaries and circulate through normal streets (minimizing the transfers) and bypassing congested areas. They can reach maximum velocities of up 100 km/h with an average velocity of 80 km/h.

Table 2. List of operational characteristics of BRT in North America and Australia

City	Year first opened	Popu-lation (Millions)	Length (km)	Costs (US$-€Millions)	Cost per km (US$Millions/km)	Average station spacing (m)	Weekday bus riders	AM PEAK HOUR BUSES	AM PEAK HOUR RIDERS	Speeds (km/h) ALL STOP	Travel time reduccion (%)
Ottawa	1983	0.7	60.0	293.0	4.9	2.100	200,000	180-200	10,000	39	N/A
Seattle	1990	1.8	3.4	450.0	132.4	1.180	46,000	70	4,200	21	33%
Adelaide	1989	1.1	11.9	53.0	4.5	N/A	30,000	N/A	4,000	80	38%
Brisbane	1990	1.5	16.9	200.0	11.8	1.680	60,000	150	9,500	55 - 58	70%

Source: Canales (2006) and Levinson *et al* (2003).

3. BRT POLICIES AND IMPLEMENTATION IN EUROPE

In the case of the European cities, its greater territorial compaction is recognized in the metropolis. This characteristic is fundamental in the moment of planning the systems of surface urban public transport. Besides in Europe it is more frequent to find a high ecological sensibility on behalf of the authorities, in almost all of Europe the public transportation is a definite tool and exploited by the governments and users, to minimize the problems of an uncontrollable traffic growth. The BRT systems are in direct competition with networks of urban and regional railroads and LRT, that present a great development on this continent.

Paris – France

The platform reserved Trans-Val-of-Marne is a bi-directional corridor of 7 m wide. It was projected to receive a light train in the future in case of increasing congestion, with 11.5 km of reserved platform and with priority in the intersections by means of traffic signal coordination. It has been chosen as an experiment of various systems of guided transportations.

Leeds – UK

The super bus uses separate lanes with a mechanism guide of strategic locations on the route, and is operated by five bus lines in a common area. It enables the use of conventional or special buses (rail guide infrastructure). The system conserves space (normal rail 3.5 m and rail guide 2.6 m). It creates flexibility, which accommodates buses of all distances: short, medium and long.

Dublin - Ireland

The network of Quality Bus Corridor (QBCs) is a conglomeration of 11 corridors with a high frequency, one bus lane and adequate design of stop and great legibility of the network. Busways are very beneficial in that they allow the buses to enter and leave the intersections ahead of other traffic. Traffic signal regulation and selective detection allow for bus precedence in the intersections. Buslanes are distinguished by prohibiting turns, different colors, and separate surface areas.

Stockholm - Sweden
The network truck buses has four lines (blue) with simple numbers (one-four) that circulate through the main streets (a clear and understandable by its users). The network has 24.1 km of segregated lanes, including the coordination of 140 traffic signals of which 70 are given transit priority. The stops are painted red in order to facilitate clarity and comprehension. Boarding is permitted by the three doors. The buses use clean fuels such as ethanol (lines 1-3-4) and methanol (line 2).

Table 3. List of operational characteristics of BRT in Europe

City	Year first opened	Popu-lation (Millions)	Length (km)	Costs (US$-€Millions)	Cost per km (US$-€Millions/km)	Average station spacing (m)	Weekday bus riders	AM PEAK HOUR BUSES	AM PEAK HOUR RIDERS	Speeds (km/h) ALL STOP	Travel time reduccion (%)
Paris	1993	8.3	12.5	90 € (93)	7.2	540	53,000	60	4,800 *	23	N/A
Leeds	1995	0.7	1.5	5.0	3.3	500*	N/A	N/A	N/A	20*	33%
Dublin	1997	1.1	100.0	150 € (05)	1.5	N/A	65,000	60*	6,700	18	22%
Stockolm	1998	1.5	24.1	82€ (92)	3.4	500	146,000	50	4,500 *	15	N/A

Source: Canales (2006) and Levinson *et al* (2003).

4. SPANISH CASE STUDY

4.1. BUS-HOV Lane In Madrid

The first attempt in Spain to construct a segregated rapid bus lane was made in the A6 corridor of Madrid in the mid nineties (from the city center through the Northeast). It was the zone that showed the lowest population density in the region (314 hab/km^2) and it concentrated the highest motorization rate (413 veh/1000 inhabitants).

This segregated infrastructure has been used uniquely by buses and, in some stretches, by vehicles with high occupancy rate (at least two passengers per vehicle). This infrastructure is operated in direction towards Madrid during the morning, while it serves the opposite flow during the evenings. The total length of the bus lane is 17.5 km. The central stretch (9.8 km long) is composed by 2 reversible lanes of 3.5 meters wide used by both buses and high occupancy vehicles (HOVs). The stretch closer to Madrid is reserved only for buses and it is constituted by 1 lane of 3.5 meters wide and 3.9 km long. Finally, the bus lane stretch far away from Madrid is composed by 1 lane with the same characteristics of the latest one but it is used by both buses and HOVs.

The results obtained from the opening to traffic date have been successful. In rush hours, the 60 % of the total amount of travelers enter into Madrid by the means of this specific infrastructure (buses or HOV). The total amount of 1200 buses per day using the infrastructure in 1994 has increased to more than 4000 buses in 2003.

4.2. BUS-HOV Lanes In The Main Entrances Of Barcelona

In 2003, the regional government of Catalonia and local administrations that play a role in the transport policy of Barcelona Metropolitan Area planned the construction of 3 main BUS-HOV corridors in the key entrances of the city centre. These BUS-HOV lanes are conceived functionally like the Madrid ones but will differ in the construction design. The proposed BUS-HOV lanes of Barcelona were planned enlarging the current highway platform and constructing new bridges only if a natural barrier or another highway has to be crossed. The new BUS-HOV corridors planned to be opened before 2009 and their capital costs are detailed in Table 4.

Table 4. List of bus lanes and Bus-HOV lanes planned in Barcelona

BUS-HOV lane	Transversal section	Length (Km)	Total Cost (2006 m€)	Unit Cost in (2006 m€/km)
C-58 Highway (from Ripollet to Barcelona-Av. Meridiana)	2 extra segregated reversible BUS-HOV lanes (in central reservation)	6.67	57,215	8,578
C-31 Highway (from Montgat to Barcelona Glories)	1 extra non-segregated non-reversible in direction to Barcelona(enlarging the current platform)	7.27	8,556	1,176
B-23 Highway (from Molins de Rei to Av. Diagonal-Barcelona)	2 extra segregated reversible BUS-HOV lanes (in central reservation)	--	--	--

The effectiveness of these initiatives has been assessed in terms of travel time and internal profitability rate. For example, the average current travel time and delay associated to the corridor C-31 is respectively 26 and 7.8 min. With the implementation of BUS-VAO lane, the average delay will be reduced to 2 minutes in the opening year and it will climb to 4 minutes in the 30th year from the opening date. Taking into account the capital cost, internal costs and external costs, the internal rate of return is estimated to be 14.9%.

However, these BUS or BUS-HOV lanes are not accompanied by other upgrading bus performance such as terminals, traffic signal synchronization or technological systems to reduce boarding/alighting unit times. It can be noticed that the reservation of a lane to entrance into the city centre from outlying cities is the unique BRT characteristic to be implemented in Barcelona.

4.3. BUS-HOV Lanes In Other Cities

The Spanish Public Work Ministry has been in favour of the tendency to construct new Bus lanes or Bus-HOV lanes in major cities. In this way, the Strategic Infrastructure and Transport Plan approved by National Government considers the construction of more than 250 km of new bus lanes in Madrid, those analysed in Barcelona, Málaga, Oviedo, Valencia and Cáceres. However, the development of Bus lanes in the later 3 cities has been postponed due to its negative cost-effectiveness.

Table 5. New bus-lanes corridors to be constructed in Spain

City	Length (km)	Expected cost (m€)
Madrid	138.2	740,000
Málaga	11	45,000

4.4. BRT Features To Be Implemented In Barcelona

Despite the fact that BRT systems have met a great success in interurban trips among metropolitan areas, some characteristics of BRT could produce a significant enhancement of major local bus routes of Barcelona.

Hence, the local government of Barcelona has proposed the analysis of the implementation of new operational procedures and new concepts of bus networks and systems in order to provide the most efficient service to the inhabitants.

Transports Metropolitans de Barcelona, TMB, is in charge of providing service within the urban limits of Barcelona. In 2005, the bus network was composed of 103 bus routes covering 890 km, using a fleet of 1.003 vehicles. The annual ridership for TMB bus network is more than 210 million passengers.

The bus routes in Barcelona go through different types of urban layouts that can be found in the city: only the *Eixample* has a square grid pattern, whereas other neighbourhoods in the city, specially the older ones, have a more chaotic structure. For the specific case of the *Eixample*, the sea-mountain (S-M) routes and the transversal routes turn out to follow the grid streets in a straight way, similar to other cities such as Chicago, New York, etc.

As for the service speed, although the overall average commercial speed is about 12 km/h within the bus network, there is a significant variation among line topology groups. Generally, transversal routes are faster than S-M routes by almost 40% on average. The average commercial speed in rush hour is depicted in Figure 1 in major corridors.

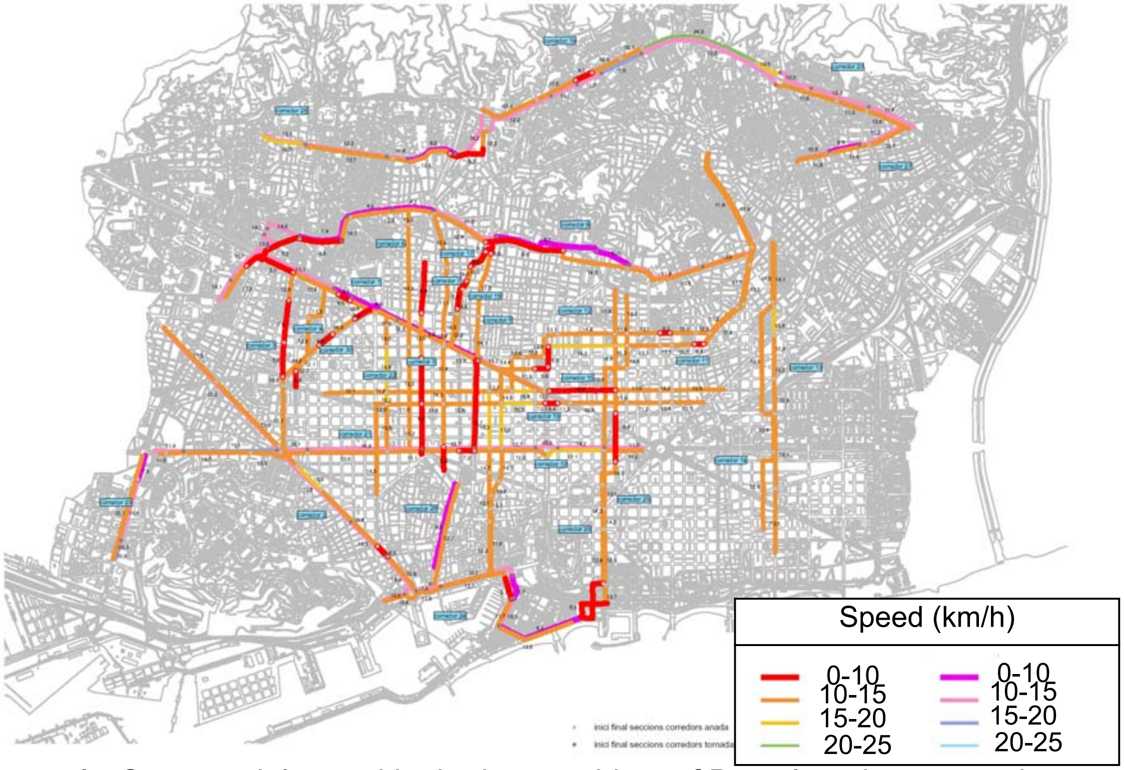

Figure 1. Commercial speed in the key corridors of Barcelona bus network.

Larger stop spacing

A recent study to determine potential upgrades and BRT features implementation to Barcelona bus network was carried out in Warlam (2005). It uses the analytic model developed by Van Ness (1999) to consider the costs associated to transport system users, administration, and operator in order to evaluate the social profitability of the bus network. In the analyses, such optimal decision variables as stop distance, bus route distance, and frequency of the service were assessed. The objective function Z that represents the minimization of total cost could be summarized by Equation 1.

$$Z = \min\left\{ c_t \left(w_a \frac{f_a (D_s + D_l)}{v_a} + w_w \frac{f_w}{F} + w_i \frac{D_c}{D_s}\left(\frac{D_s}{v} + T_s\right) + w_e T_e \right) P + c_o F \frac{1000}{D_s}\frac{1000}{D_l}\left(\frac{D_s}{v} + T_s\right) \right\} \quad (1)$$

Table 6. Variables and parameters considered in equation 1

Symbol	Concept	Value	Units
D_c	Travel distance (TMB data)	3,300	m
va	Access speed	1.1	m/s
fa	Factor access distance. It is supposed that the user will access the network from the mid point in between two different bus routes and two different bus stops.	0.25	
D_s	Stop distance (TMB data and constraints detailed in	350	m

	Saka, 2001)		
D_l	Line distance (TMB data)		
v	Maximum speed transit (TMB data)	4	m/s
Ts	Time lost at stops (Kittelson, 2003)	20	s/stop
fw	Factor waiting time	0.5	
T_e	Egress time (Kittelson, 2003)	4.72	min
w_a	Weight Access time (survey)	1.61	
w_w	Weight Waiting time (survey)	2.55	
w_e	Weight Egress time (survey)	1.58	
F	Frequency (TMB data)	8.5	veh/h
P	Travel demand per square kilometre (TMB data)	500	pax/km^2
c_t	Value of Time for travellers (Robuste 1994)	10	€/h
c_o	Operating costs per vehicle (TMB data)	4.5	€/veh-km

The original values for the variables were taken from the operator's available data, from a survey conducted to Barcelona's bus passengers and the values detailed in Kittelson (2003). Only the bus routes comprehended within the neighbourhood of the *Eixample* were taken into consideration.

The results show that the current stop spacing (350 m) would need to be increased in order to optimize the efficiency of the network in Barcelona. It would lead to lower operational costs and more attractive transit networks. Increasing it by 150m (stop spacing equal to 500m) a reduction of three minutes in the weighted total time could be achieved if the vehicle frequency is set to 12 vehicles per hour (every five minutes). Including the line spacing as a design variable, the results of minimizing total costs (operator and user time) is that the network is improved when the stop spacing is set to almost 490m and the line spacing to almost 855m.

Numerical modelling of BRT implementation in 3 main lines

The Centre for Innovation in Transport (CENIT) of Barcelona has studied the implementation of efficient strategies of high-speed urban bus lines in a high-density urban context, by transposing some elements of typical Bus Rapid Transit systems in a high-density urban context. For each strategy, the work evaluates the bus speed, the demand response to the bus travel time savings, the passenger trips generalized cost and the operative costs. In CENIT (2006), an entirely applied approach has been followed, by modelling the application of each high-speed strategy to three existing lines of the Barcelona Metropolitan Area (AMB).

The lines of study have been selected regarding the interest of the implementation of high-speed strategies and the ability to generalize our results to other contexts. Therefore, simulations have been realized on:

Bus line 15:

Line 15 is a central line that runs along important and highly congested arterial streets of Barcelona (Diagonal Avenue) and passes through high-density residential and commercial areas. It has 6 min headway (one of the highest frequency of the bus network) and its ridership is one of the most important of all TMB bus lines. Line 15 is constructed with bus lanes in a large part of its route.

Bus line 74:

Line 74 is a typical transversal line (river to river direction, parallel to the coast) of Barcelona, that runs along the high capacity urban highway of "Ronda del Mig", in which there are low traffic volumes in peak hours. It is known to be the TMB line that shows the highest ridership. The line runs with 7 min headway and is not constructed with any kind of segregated running-way.

Bus line 10:

Line 10 is a traditional "sea-mountain" line. Compared to the two other studied lines, this one is characterized by lower density traffic and higher transit vehicles speed along the route. It passes through lower density areas. The line runs with a headway of 8 min and it is not equipped with any kind of segregated running-way.

For the three lines, 8 different high-speed line strategies have been simulated. Each strategy is the result of the combination of an infrastructural arrangement and a bus stop spacing parameter, chosen among the following:

Infrastructural arrangement:

- *IA-0. "Do nothing" strategy*: current configuration of the line
- *IA-1."Minimal BRT" strategy*: implementation of *bus lanes* (segregated but non physically separated running-way) along some high-priority sections of the route; mixed traffic in other parts; double boarding platform in the main bus stops; no bus signal priority.
- *IA-2. "Medium BRT" strategy*: implementation of *bus ways* (physically segregated running-way) along the high-priority sections of the route and of *bus lanes* in other parts; double boarding platform in the main bus stops; bus signal priority in the high-priority sections.
- *IA-3. "Maximal BRT" strategy*: implementation of *bus ways* along the whole line, double boarding platform in the main bus stops, bus signal priority in the whole line, fare collection with prepayment system in all the bus stops.

Bus stops spacing:

- *Current bus stop spacing* (300m)
- *Larger bus stop spacing* (600m): suppression of approximately half of the bus stops.

A demand responsive modeling method has been developed for the simulations based on a micro simulation tool of bus transit and the *TransCAD* software. It can be divided in four steps:

1. Implementation of the physical arrangement, transit and traffic parameters of the line in the model, by using the GIS functionalities of *TransCAD.*
2. Travel time modeling; a method has been defined that permits to separate the effect of priority measures on the different kind of transit delays (congestion delays, right-turn delays, bus-bus interference delays, etc.).
3. Transit demand evaluation and assignment to the network. The demand response to travel time savings is modeled with an elasticity method.
4. Calculation of passenger generalized cost and operative cost from the output of the transit demand assignment.

The modeling results for the three lines are resumed in Table 7. The main conclusions that can be pointed out are:

1. In lines 15 and 74, the implementation of the maximal BRT strategy increases average bus speed by 25 /31% with current bus stop spacing, and by 33% / 41% with a 600 meters bus strop spacing. Therefore, implementation of such strategy is efficient.
2. In line 10, implementation of BRT strategy is not efficient (no more than a 3% increasing with infrastructural change).
3. Therefore, it can be concluded that the worst current conditions of bus transit are (large delays, low speed, and congestion), the more efficient implementation of bus preferential treatments will be.
4. Double loading area can increase bus speed by values up to 35% in high bus transit volumes sections.
5. Physical separation of the bus running-way (passing from a *bus lane* to a *bus way)* joined to Bus Signal Priority improve bus speed by values from 20% to 30% in high traffic flow sections.
6. Larger bus stop spacing improves speeds by 1-2 Km/h. Nevertheless, the model shows that this improvement can not compensate the lost of ridership due to the passengers sensibility to the increase of their access time.

Table 7. Results derived from the modelisation of 3 bus lines

	300 m bus stop spacing				600 m bus stop spacing			
	IA-0	IA-1	IA-2	IA-3	IA-0	IA-1	IA-2	IA-3
Line 15								
Average bus speed	10,8	11,4	12,8	14,1	11,5	12,2	13,8	15,2
Total ridership (both directions)	2835	2881	2967	3061	2384	2422	2489	2560
Average generalized cost of a passenger (€)	6,15	6,00	5,73	5,44	6,38	6,23	5,98	5,72
Total variable operation costs (€)	459,7	441,9	406,7	392,6	419,1	426,2	390,0	375,0
Number of necessary buses	19	18	16	15	17	17	15	14
Line 74								
Average bus speed	12,8	12,2	14,1	15,8	14,2	13,2	15,2	17,1
Total ridership (both directions)	2688	2688	2798	2847	2172	2101	2243	2279
Average generalized cost of a passenger (€)	6,12	6,27	5,80	5,63	6,35	6,53	6,05	5,88
Total variable operation costs (€)	381,4	375,9	340,6	325,9	341,6	397,1	359,4	306,9
Number of necessary buses	*15*	*15*	*13*	*12*	*13*	*16*	*14*	*11*
Line 10								
Average bus speed	15,1	14,8	15,4	15,6	16,4	15,8	16,3	16,4
Total ridership (both directions)	1402	1402	1402	1420	1149	1151	1151	1151
Average generalized cost of a passenger (€)	5,77	5,79	5,72	5,68	5,94	6,00	5,95	5,93
Total variable operation costs (€)	295,3	293,3	297,8	298,9	276,1	300,2	275,8	276,6
Number of necessary buses	11	11	11	11	10	11	10	10

5. CONCLUSIONS. GUIDELINES TO DEVELOP AN EFFICIENT BRT SYSTEM IN EUROPE

The analysis of the international experiences show that the costs per kilometre of the BRT systems in Europe and South America are even (4 M€/km) though the annual demand in Europe is significantly less than that of South America (values of 100mpax/day and 300mpax/day respectively). This is due to the already existing public transportation in Europe.

In dense and compact environments, like European cities, the BRTs are more difficult to implement. Priority should be given to the bus before the private vehicle, because the general interest should take precedence over the private interest.

Of the world experiences had with BRT and especially with bus only lanes and BUS-HOV, one can identify some of its own criteria for the efficient design of lanes reserved for the circulation of buses for entrance to large cities from the outskirts.

Corridors:

- Radial corridors with periods of important points in urban areas with more than 1 million inhabitants and high concentration of employment in the extreme areas.
- Corridors with a high degree of car ownership and high incomes of the families.
- Corridors with existence or forecast of important congestion (the velocity in rush hour should be lower to 50 km/h)
- Corridors with a high present number of vehicles with high occupation (minimum of 400-800 buses/cars shared per hour)
- Corridors with an inexistent way of collective transportation that can be improved with reduced inversions
- Corridors with unbalanced flow in the entrance and exit direction.

Exploitation and construction:

- Global savings of time with the bus only BUS-VAO lanes are superior to the occasional delays of conventional bus only lanes.
- A BUS-VAO lane should be built if the new lane is capable of carrying a minimum of 800 vehicles per hour (or around 1800 people per hour) during rush hour after the opening of the lane.
- Some prices of construction should be kept to a reasonably, lower level in comparison with alternatives such as a railroad (approximately 2 million euro/km).

In reference to the establishment of the BRT systems characteristics in corridors operated by a line of urban layout to increase their velocity the following characteristics are emphasized:

- The application of BRT measures is recommended in corridors with high conflict car-bus and bus bunching, low commercial velocities (12 km/h) and an aggregated time-headway less than seven minutes. The integral BRT strategy permits a 25%/31% earnings with the current stop spacing, and even 33%/41% with even greater spacing.

- In these situations (such as bus line number 74 and 15 of Barcelona), the actions of implementation of double boarding platforms and alighting of passengers should be carried out in the sections in which the sum of all the frequencies of all lines is more than the 60% of its capacity of the infrastructure. This action can increase the commercial velocity between a 5 and 35% in the sections in which very important buses pass.

- The physical segregation of an associated bus lane to a system of traffic signal priority permits an increase in the velocity from 20 and 30% with regard to a situation with non-segregated bus lanes. The effect of the implementation of physical barrier to segregate the bus lanes is a medium increase of 20% of the velocity. Together with to a prepayment system the increase of speed is about 30%.

The increment of the spacing among stops to some 500 meters allows for the earning of approximately 1 km/h of commercial velocity although it would produce an increase of the accessing passenger cost.

REFERENCES

Canales, C. (2006) *Conclusions of International conference about efficient bus systems*. Barcelona, February 2006. Revista movilidad sostenible y segura. Barcelona. In Spanish.

CENIT (2006). *Enhancement of bus speed in Barcelona. Study of 30 main corridors*. Work paper for TMB. Centre for Innovation in Transport. Technical University of Barcelona. In Catalan.

Cristóbal, C., S. Lecler, S. Sedin, B. Tebb, R. Lopez, H. Matallana (2004). *International experiences in urban bus networks*. Carreteras, vol. 133. pp. 1- 117. Madrid, Spain.

Kittelson & Associates (2003). *Transit Capacity and Quality of Service Manual*. 2nd Edition. Transit Cooperative Research Program. Transportation Research Board, Washington.

Levinson, H. S., S. Zimmerman, J. Clinger, J. Gast, S. Rutherford and E. Bruhn (2003*). Bus Rapid Transit. Volume 2: Implementation Guidelines.* Transit Cooperative Research Program. Transportation Research Board. Washington**.**

Robusté, F. (1994). *Transport planning.* CPET. Civil Engineering School, Technical University of Catalonia, Spain.

Saka, A. (2001). *Model for determining optimum bus-stop spacing in urban areas*. Journal of Transportation Engineering, May/June 2001, pp. 195-199.

Van Ness, R. (1999). *Larger stop spacing in urban transit networks: why?* Trail Research School, Delft.

Warlam, R. (2005). *Bus network operations and management in Chicago and Barcelona: The effects of larger stop spacing on social profitabilit*y. Graduating thesis. Civil Engineering School, Technical University of Catalonia at Barcelona, Spain.