BUS FOR HLS LINES IN URBAN CONTEXT

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ABSTRACT

In many european cities, public transportation systems on reserved way are spreading; interesting experiences are those relating to BHLS, thanks to their superior performance, compared to traditional bus lines, and relatively low cost of implementation and management. The paper offers some insights on BHLS lines vehicles, and their related performance and potential. It is part of research activities inside European Project COST TU603 (www.bhls.eu).

Keywords: Buses with a High Level of Services, BHLS, Public transport, Bus performance, ITS

1. INTRODUCTION

The experiences of buses with high level of service (BHLS) is spreading throughout Europe. Different from the American Bus Rapid Transit (BRT) for several reasons, European BHLS are proposed as an alternative urban public transportation system, particularly in medium and small cities where tram solution is difficult to implement.

BHLS are not intended as a substitute for other types of public transport such as trams or ordinary buses, but they may represent a a good alternative in relation to a specific context. The choice of a technology must address with many variables of wich are analysed in the feasibility study.

In this paper, attention is paid to these proposed systems, with hints of representative applications in european urban environments. Attention is further focused on vehicle component, highlighting the innovation elements arising from the interaction between demand and manufacturing companies.

Some new performance models were developed, and they may contribute to simulate the operativity of a transit system.

2. KEY FEATURES OF URBAN PUBLIC TRANSPORT. BRT AND BHLS

In order to enhance urban public transportation, many government authorities try to create reserved lane systems in order to limit the excessive and often disruptive presence of private car,. The choice of more efficient technologies is never easy. The technological solution must be related to:

- desired demand;
- dimensions of the served urban area;
- density and settlements along the line corridor;
- morphology of the land and urban fabric,
- characteristics of the population.

The idea of a transport system able of providing a service level higher than that of conventional bus services along major corridors, in terms of frequency, comfort, commercial speed, reliability, accessibility, has already established in America (Diaz 2009). Transport networks were made based on a hierarchy with primary lines (HLS) and more traditional feeder lines. In North America BRT lines focused on attributes such as target speed and comfort of travel (Levinson et al. 2003). In South American wide urban areas, the choice of BRT was due to the unavailability of larger financial resources for ordinary subway systems. The features include:

- a reserved and protected roadway;
- stops functional organization similar to subway stations;
- use of centralized control systems and ITS technologies;
- integrated service management; and
- high frequencies and speeds.

This aim to increase lines transportation capacity responds to a fairly strong demand that could not be met by traditional systems.

European BHLS detach themselves from the dominating rapidity concept, which is the heart of the american BRT system, and aims to fulfill needs for quality, service reliability, operational flexibility and positive impact on urban environment needs. In some aspects it tends to close the tram performance levels, limiting costs and the issues related to rails. The idea of structuring transport networks on a hierarchical basis persists, however. A common feature lies in centralized vehicles control system. Information about vehicles status and location is continuously monitored and directs real-time news to users on board and at stops.

3. BHLS EXPERIENCES IN EUROPE

Although there is no settled definition of BHLS yet (Babilotte et Rambaud 2005), when referring to these systems, a high degree of separation of bus lanes able to offer higher performance than traditional bus is expected. A wealth of experience confirms this idea, and systems features vary according to the differences in the composition of the system's features. Firstly, substantial differences in terms of infrastructure, related to both urban context and desired service levels, can be observed. Type and geometry of roadway, inclusion of reserved lanes and type of intersections are among the key factors that come into play. The roads can take on different arrangements, depending on the degree of separation from other transport systems: there are bus only lanes and lanes also opened to other vehicle categories such as taxis, bicycles and emergency vehicles. A degree of physical protection can be determined through different floors and/or colors of the roadway, light separators elements such as curbs, speed bumps and warning signs, or non-crossable elements avoiding interferences. As there are not many resources available to ensure the respect of prohibitions, reserved and protected lanes are essential to keep high service levels achievable to BHLS, in relation to the regularity of travel and commercial speed.

A BHLS line is often an important opportunity for the rehabilitation of public spaces along the corridor served. This typically tends to redevelop the entire route, creating cycle lanes and pedestrian areas, improving urban design, better equipping stops, and reducing road space for private car use.

3.1. BHLS experiences in Germany

The first commercial kerb guided bus operation started in 1980. The city of Essen created a fully protected way (the O-Bahn) on a peri-urban path parallel to a motorway. The infrastructure is made of prefabricated concrete beams, arranged in series for a total length of 4 km, and the curb side is used as a directional constraint for vehicles equipped with guide-wheels.

OPNV Trasse operates in the city of Oberhausen sharing the road with tram (Figure 1). Made up of 125 buses, of which approx half are articulated, the system carries an average of 40.2 million passengers per year.

Figure 1: OPNV Trasse in Oberhausen

The Metrobusse BHLS system of Hamburg uses articulated and double-articulated vehicles (Figure 2), all equipped with user information system. The high frequencies results in a considerable transport capacity: an average of 60,000 passengers uses the system daily.

Figure 2: Hamburg XXL

3.2. BHLS experiences in France

Rouen BHLS system Teor (3 lines, of which 45% are on protected lanes) is one of the most interesting and extended in Europe. Teor vehicles has semi-automatic guidance: an optical unit recognizes the way through two dotted lines placed down the centre of the lane. Automatic guidance is activated only at stops and allows perfect vehicle alignment with platform. The network moves about 45,000 people every day.

Nantes Busway was created in 2006 from the disposal of a highway that penetrated the city center. A special type of intersection, with roundabouts and diametrical crossing for buses, was also adopted (Figure 3). 20 articulated buses travel the line carrying an average of 25,000 passengers daily.

Figure 3: Bus crossing a roundabout in Nantes

Trans Val de Marne (TVM) BHLS line is located near Paris. It runs for 85% of its length on reserved lanes. 39 articulated buses operates carrying an average of 65,000 passengers daily.

Triskell BHLS has operated in Lorient since 2007, crossing the city centre on reserved lanes. Like Nantes, there is a particular priority system at intersections, crossing roundabouts with or without traffic lights. Great attention was given to the stations' design. In addition to their transport function, they represent meeting places for local inhabitants.

3.3. BHLS experiences in Sweden

In Jonkoping (Figure 4) a 3-line BHLS network with 100 vehicles operates. Current low traffic counts on the road network, combined with the priority systems at intersections, allow the service to achieve good performance even without completely reserved lanes.

Stockholm Blue Bus BHLS network was designed to support the metro in the poorly served suburbs. It has 4 lines. Articulated vehicles are equipped with automatic location system. The network is moving some 150,000 passengers each day.

Goteborg 4-lines BHLS system has an infrastructure made of rounded curb stone. The system uses double-articulated buses with a capacity up to 165 passengers, moving around 64,000 passengers daily.

Figure 4: A Jonkoping BHLS vehicle

3.4. BHLS experiences in the United Kingdom

Located east of Leeds on two major road corridors (Figure 5), Quality Bus Initiative provides the main transport link for many residential communities along the corridor, serving some 100,000 residents. The scheme comprises bus lane and cycle lane, bus priority at junctions through selective bus detection, over 330 enhanced stops and double-decker buses fitted with guide wheels, low floor and full accessibility. There is evidence of modal shift away from the car with 7% of users indicating that they would have previously made their journey by car.

In the Thames Gateway area of Kent, 16.000 passengers are carried daily through two Fastrack lines . Signal priority, reserved lanes (24% of the total), and dedicated busways (32% of the total) allow Fastrack vehicles to avoid traffic. The fleet is made up of 26 articulated vehicles, all equipped with passenger information screens, voice announcement systems and CCTV. Tickets are sold by the driver, but passengers can also buy tickets from roadside machines at certain bus stops or through their own mobile phones.

The city of Manchester has created 24 lines of Quality Bus Corridors (QBC). The 281 km network is characterized by reserved lanes, priority systems at intersections for its double-decker vehicles, wide waiting areas allowing easy user access and information systems on-board and at stops.

Figure 5: Guided bus corridor in Leeds

3.5. BHLS experience in Ireland

A network of Quality Bus Corridor (QBC) runs along the main roads of Dublin. The network covers about 200 km and includes 15 lines. The vehicle fleet consists of 52 double-decker buses (Figure 6). The number of daily passengers is approximately 35,000.

Figure 6: Dublin double-decker bus

3.6. BHLS experience in Switzerland

In Zürich, BHLS Line 31 is characterized by dedicated lanes and priority systems at intersections and it was created in 2007. Information on status and position of vehicles is broadcasted in real time to information panels on-board and at stations. A number of 35,000 passengers is carried daily by high capacity double-articulated buses (Figure 7).

Figure 7: A double-articulated bus in Zürich

3.7. BHLS experiences in Spain

In 1995, for the first time in Europe, a corridor reserved for the movement of buses was created within a highway that goes from the outskirts to the centre of Madrid. The system, called Bus-Vao (High Occupancy Vehicle), get over 120,000 daily passengers. A new project aims to create a typical BHLS network, involving the insertion the addition of 8 new lines serving the outskirts of Madrid.

In 2008 the city of Castellón implemented a BHLS line (TVR) with trolley in reserved lanes and optical guidance system. The line has 5 stations, connects the downtown area with the university (with only 2 vehicles in service) and moves an average 3,200 passengers per day.

Figure 8: Optical guided trolleybus in Castellon

3.8. BHLS experiences in the Netherlands

Eindhoven was the first city to implement a magnetic guidance system. Fleet is made up of 11 single-articulated (Figure 9) and 1 double-articulated vehicle. Vehicles mainly drives on bus lanes, with a pre-programmed route continuously verified by magnets set into the asphalt.

The Zuidtangent is a suburban route that offers high reliability and an over 40,000 passengers daily ridership. Zuidtangent buses run on dedicated bus lanes from Haarlem to Schiphol Airport and use normal roads and motorways for the rest of the route. They have priority at road crossings throughout.

A network of High Quality Bus infrastructure, called HOV Om de Zuid, connects Utrecht main railway station with the university in the east suburbs, running double-articulated vehicles through segregated bus lanes. The system provides a ridership of 45,000 pax/day.

Figure 9: Articulated bus in Eindhoven

Table 1 provides an overview of the BHLS main features (length, average distance between stops, frequency and commercial speed) in different European contexts.

Table 1: European BHLS systems

	L (km)	D (m)	q (runs/h)	v (km/h)
Essen	4.0	800	6	30.0
Oberhausen	6.8	1000	30	34.0
Hamburg	15.0	510	18	18.8
Rouen	29.8	530	10	17.5
Nantes	7.0	500	15	22.0
Paris	22.0	700	15	22.0
Lorient	4.6	270	6-15	19.0
Jonkoping	39.2	440	2-6	22.0
Stockholm	79.7	450	6-15	16.5
Goteborg	16.5	700	6-20	21.0
Leeds	2.6	-	2-6	18.5
Kent	25.0	-	4-6	18.3
Manchester	15.5	310	6-10	18.4
Dublin	200.0	250	20-30	17.5
Zürich	22.2	400	6- 8	16.3
Madrid	16.1	450	17	33.5
Castellón	2.0	500	7-12	18.0
Amsterdam	41.0	1900	10	36.0
Utrecht	12.5	360	30	22.7

4. BUS FOR HLS LINES

A BHLS vehicle is not simply a bus. Its tecnology affects system performance, as it underlies the ability to meet demand, and determine some design choices related to the infrastructure.

The choice of vehicle layout may be influenced by the characteristics of the infrastructure (slope, winding, cross-section). Propulsion system influences variables of great interest for urban communities, such as pollution production rate. The vehicle equipment in terms of technological components are fundamental as regards comfort, safety and information. System performance, including commercial speed, frequency, and transport capacity, are generally significantly higher than traditional urban bus lines, although there are a wide range of solutions.

4.1. Vehicle layout

Generally a BHLS line tends to use large vehicles, such as articulated and double-articulated buses. They are the preferred as they enhance the transport capacity, creating an attractive image of service and reducing costs. Vehicles with a length up to 25-26 m are commercially available. There are some problems with interaction between vehicle and infrastructure, so a lot of attention is paid to parameters such as curvature radius and overhang dimensions.

Interior vehicle design (Figure 10) is related not only to the level of comfort offered and degree of security but also to expected peak demand. It is expressed through the distribution of spaces: seats, standing area, cockpit, space for disabled people, corridors, etc. Passengers prefer seats, but their number is limited. Even if a standard of 6 people per square meter is possible, BHLS lines tend to avoid overcrowding.

Positioning the engine in the rear of the vehicle allows the construction of fully low floors, making simple access for wheelchairs and disabled people possible.

Quality features such as tram-like sliding doors, closed area for the driver, soft and indirect lighting, confortable seats, insulation with double-glazed windows, tend to become widespread.

Manufacturers guarantee legal security standards (corridors, number and type of doors) inside vehicles. Among the innovative features there is the possibility of having doors on both sides, making boarding and alighting operations easier and faster.

Figure 10: Interior layout in an articulated vehicle

4.2. Guidance systems

Several technological solutions are aimed to ensure better performance of vehicles, in terms of trajectory control and approach, longitudinal and side precision dockings at stops, even allowing in some cases the automatic guidance of vehicles, are available today.

Among the mechanical systems, guide wheels with vertical axis (Figure 11) run along the curb side of the infrastructure, ensuring the trajectory of the vehicle. At bus stops with appropriate kerb height, the vehicle's guide wheel allows the driver to 'dock' against the stop achieving a uniform close contact to allow easy, level boarding.

Figure 11: Curb guided system in Essen

Optical guidance systems (Figure 12) use a camera located on front of the vehicle, a specialized image processing software, an automatic drive device. Through image recognition (two dotted lines in the middle of the lane) the vehicle is guided along the way. However, the driver can take manual control of the vehicle at any time. The system makes the docking into the stop easier, ensuring minimum distance of approach, avoiding collisions with the dock and increasing commercial speed.

Figure 12: Optical guidance bus in Rouen

In magnetic systems (homologation in progress), guidance is provided by magnets placed in the roadway and in close sequence along the route, and magnetometers placed on the bus (Soulas 2003). Magnetometers detect the magnetic field generated by the devices drowned in the infrastructure. The magnetic transducer converts signal into information for the automatic drive device. Automatic guidance can be used along entire line or can be enabled only in specific sections, such as stopping and linear sections.

4.3. Propulsion Systems

Propulsion technology has a deep impact on system performance in relation to operating costs, maintenance, environmental impacts.

The most common system uses an internal combustion engine, which drives a torque converter connected to a 4, 5 or 6 automatic transmission linked with a transmission shaft. Power outputs usually range between 180 and 250 kW (up to 350 kW for articulated vehicles operating in hilly places).

Today alternatives to traditional diesel oil are today commercially available (i.e. low-suphure diesel, bio-diesel, etc.), allowing considerable reductions of pollutant emissions. Another type of fuel used is natural gas (CNG), typically stored in large cylindrical tanks placed on vehicle's roof. CNG has environmental, economic and noise advantages. But these vehicles are still not the best solution because the tanks reduce the passenger capacity, problems may arise at certain temperatures and certain slopes, and vehicles require long refuelling times.

Electric and hybrid vehicles are preferred, as they limit pollutants emissions. Figure 13 shows the functioning of different propulsion systems.

Electric buses can use electricity by means of an overhead wire (trolleybus) or an on-board storage system, i.e. a battery. Their most prominent advantage is that they produce no emissions at their point of use. Thus the environmental impact of electric vehicles lies primarily in the electricity generation, through which, for instance, greenhouse gases are released. Exact nature and extent of these impacts depends on the means of electricity production: the use of renewable energy increases overall environmental efficiency.

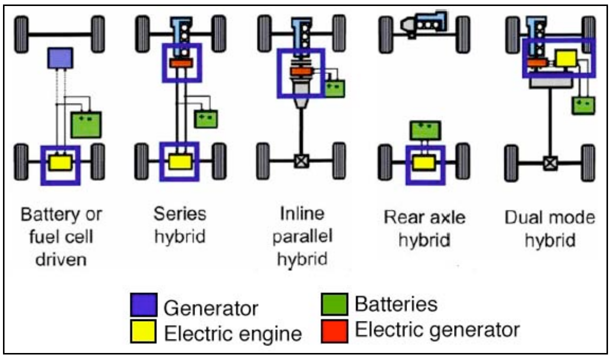

Figure 13: Alternative propulsion systems

In trolleybuses, two wires and pantographs are required to complete electrical circuit. This differs from a tram, which normally uses the track as the return part of the electrical path. Trolleybuses are advantageous on hilly routes, more effective than diesel engines in providing torque at start-up. Trolleybuses rubber tyres have better adhesion than a tram's steel wheels, giving them better climbing capability and braking. A further advantage of trolleybuses is that they can generate electricity from kinetic energy while braking (regenerative braking).

In battery-powered electric vehicles, energy can be stored onboard the vehicle. When required, energy is drawn from the batteries and converted to motive power by the use of an electric motor. Although full-sized battery-electric buses have been successfully operating, their performance limitations make them preferable for routes requiring only minibus vehicles and small operating ranges.

A dual-mode vehicle can run independently on power from two different sources, typically electricity (from overhead lines or batteries) alternated with conventional diesel fuel. Many modern trolleybuses are equipped with auxiliary propulsion systems, either using a small diesel engine or battery power, allowing a limited off-wire movement.

Hybrid vehicles incorporate on-board equipment to capture the energy that is normally lost through braking or coasting, and store it in batteries or ultra capacitors. They use both an internal combustion engine and a battery/electric drive system to improve fuel consumption, emission, and performance. These vehicles are classified by the division of power between sources: in parallel hybrids, sources operate to simultaneously provide acceleration, instead of series hybrids, where one source exclusively provides the acceleration and the second is used to augment the first's power reserve. The sources can also be used in both series and parallel as needed.

A fuel cell bus uses hydrogen to produce electricity, powering its onboard electric motor. This vehicle emits fewer pollutants, producing mainly water and heat. But the production of hydrogen would not be economically and environmentally convenient unless the hydrogen used in the fuel cell were produced using only renewable energy.

Currently, internal combustion engine is still the most used propulsion system. Hybrid and fuel cell technologies are still in prototype stage.

4.4. ITS technologies

Although not strictly required for a BHLS line, the use of Intelligent Transportation Systems (ITS) is becoming important, expecially with the increase of a service's complexity. ITS allow to make a large number of operations. It is possible to:

- know in real-time the vehicle's position and speed;
- activate priority systems at intersections;
- constantly connect driver and control center;
- know technical status of vehicles;
- acquire data for the evaluation of efficiency, reliability, consistency, security, vehicle's degree of utilization;
- provide user information at stops, such as waiting time; and
- provide user information on-board (Figure 14), such as time to next destinations.

The ITS effectiveness depends on the functionality of central control center. There are also specific components aimed to limit timewasting.

Figure 14: On-board real time information system

For example, specialized ticketing machines (Figure 15) increase service efficiency, especially during peak hours, avoiding the sale from the drive. Regarding tickets validation and checking, the trend is to avoid traditional on-board control. Devices limiting access to waiting areas exclusive to ticket holders can be used. Users flow controls can also be implemented through Automated Passenger Counters (APC), allowing a timely monitoring of transportation demand and the resulting measures to optimize operations.

Figure 15: Electronic ticketing validation machines

Video-control systems (Figure 16) became frequent in BHLS systems. Besides being useful for system management, they act as a deterrent against vandalism or criminal actions. Cameras provide complete coverage of buses and stations, operating real-time connections with control centers or video recordings.

4.5. On-board equipment

BHLS tends to be equipped in a richer way than traditional buses. Beside ordinary items such as first aid kits, fire extinguishers and "break-glass" hammers, there are baskets, jump seats, ticket vending machines, spaces and buttons for disabled users, audio-visual dynamic information systems and manual or automatic devices for the activation of wheelchairs ramps. Sometimes the carriage of bycicles is permitted on buses, but as a BHLS operates in highly crowded urban contexts, this solution is impractical.

Figura 16: On-board vehicle camera

4.6. Vehicle Performance

BHLS are characterized by higher performance than ordinary buses, in terms of commercial speed, vehicle and line capacity, energy consumption, emissions, comfort offered to passengers. Higher commercial speed comes from measures such as lanes protection, priority at intersections, reduction of boarding/alighting times and higher distance between stops.

Most of the elaborations proposed in this paragraph come from a COST (Cooperation in Science and Technology) database, created as part of Action TU0603. Data has been enhanced through a scientific research in Zürich.

The single vehicle length affect vehicle capacity. (Figure 17). Moreover, it is possible to relate the whole line capacity with runs frequency, for each type of vehicle (Figure 18).

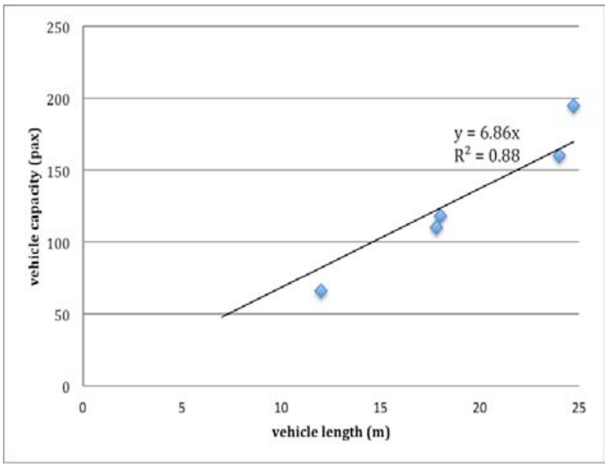

Figure 17: Vehicle capacity vs vehicle length

Many different studies identify speed as the main affecting factor on fuel consumption. The speed achieved by a vehicle is the result of interactions between factors like congestion, characteristics of vehicle and infrastructure, user behaviour and uniformity of running.

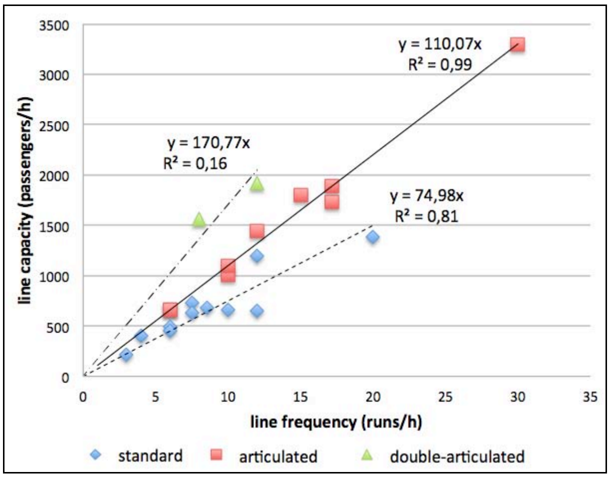

Figure 18: Line capacity vs line frequency

Several empirical models demonstrated that specific fuel consumption is relatively high at low speeds due to congestion. Moreover, consumption is influenced by vehicle size (Figure 19).

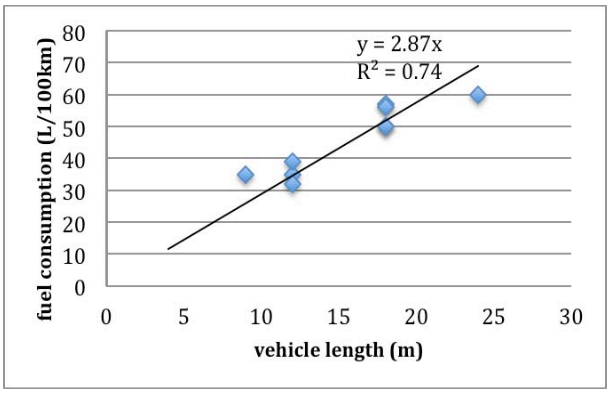

Figure 19: Fuel consumption vs vehicle length

Assuming an increase of 1.44 tons for each meter of length (resulting by a specific correlation analysis), it is possible to relate fuel consumption to vehicle gross weight, as shown in Figure 20.

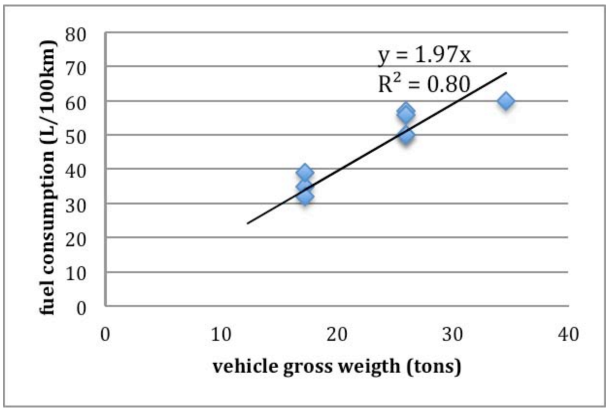

Figure 20: Fuel consumption vs gross weight

Other vehicle factors that give an important contribution in affecting the amount of fuel consumed during a trip are:

- air conditioning, which increases vehicle weight and is directly driven by the engine, with an increase of required energy of about 10-15% (Wilbers 1999);
- low tyre pressure, that increases vehicle rolling resistance and increased fuel consumption by 5–10 % (Nylund 2007);
- aerodynamic profile, affecting the air resistance acting on the vehicle;
- age of vehicle, as performanc decreases due to the wasting away of its component;
- number of stops (Figure 21): for a given distance, an increase of stops implies more acceleration-deceleration processes thus a relevant effort to achieve desired speed;
- priority at intersections: the higher the number of priorities at intersection the lower the fuel consumption; and
- congestion level: when the vehicle is embedded in flow, its running is disturbed and irregular, with many acceleration-deceleration processes.

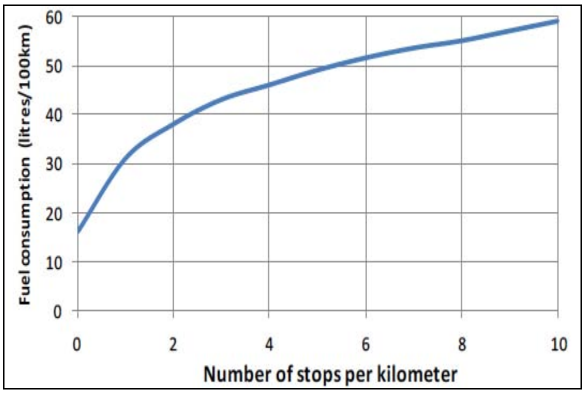

Figure 21: Fuel consumption vs stops per kilometer (Société de Transport de Montréal 2009)

European emission standards indicated in Table 2 define the acceptable limits for exhaust emissions of new vehicles sold in EU member states. EEV is the acronym of enhanced environmentally vehicle.

Table 2: Emission standards (g/kWh) for diesel buses. Source: European Environment Agency

	CO	HC	NO_x	PM
EURO I (1992)	4.5	1.10	8.0	0.36
EURO II (1998)	4.0	1.10	7.0	0.15
EURO III (2000)	2.1	0.66	5.0	0.10
EURO IV (2005)	1.5	0.46	3.5	0.02
EURO V (2008)	1.5	0.46	2.0	0.02
EEV (1999)	1.0	0.25	2.0	0.02
EURO VI (Jan 2013)	1.5	0.13	0.4	0.01

As regards to noise, that produced by a standard bus reaches values between 80 and 85 dB, whilst that produced by an electric propulsion vehicle ranges between 60 and 70 dB. Fuel cell vehicle noise is rather close to zero.

A road enlargement is required in a curve (Figure 22). For an articulated bus it is given by:

$$e = \sqrt{(p_2^2 + [\sqrt{(R + \frac{L}{2}) + p_1^2 - o^2} + \frac{L}{2}]^2} - (R + L) \qquad (1)$$

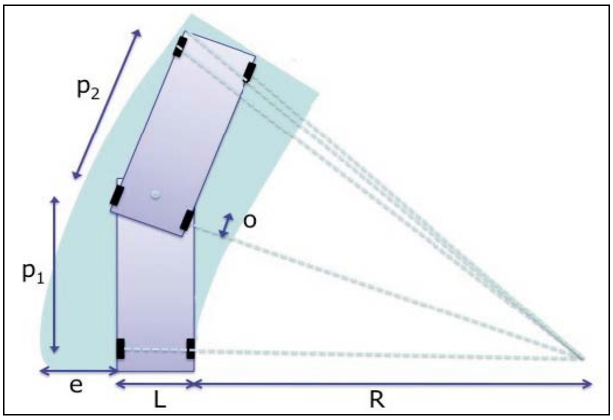

Figure 22: Road enlargement for articulated bus

The turning radius tends to increase with the length of the vehicle when passing from standard to single-articulated vehicle (from 9 to 11.2 m). In double-articulated buses, the peculiar partition of vehicle allows to keep radii on lower values (Figure 23). A further reduction of turning radius can be obtained by vehicles with all steering axles.

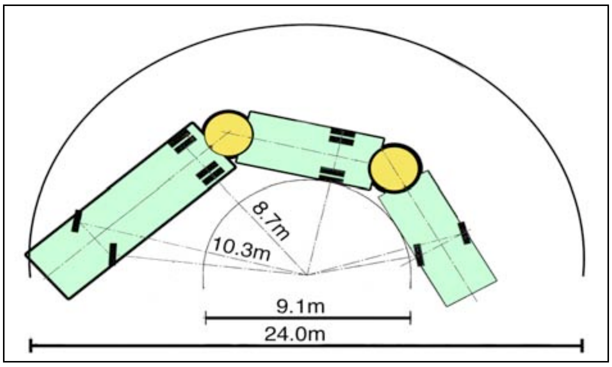

Figure 23: Double-articulated minimal turning circle
Source: elaboration on a Hess leaflet basis

Two main factors influence the motion on uphill roads. In relation to the variation of slope, front and rear overhangs impose the maximum angle (Gattuso 2008):

$$\alpha \leq min\ (\alpha_1,\alpha_2) \qquad (2)$$

with: $\alpha_1 = arctg\ (h/s_a)$ $\alpha_2 = arctg\ (h/s_p)$ (Figure 24)

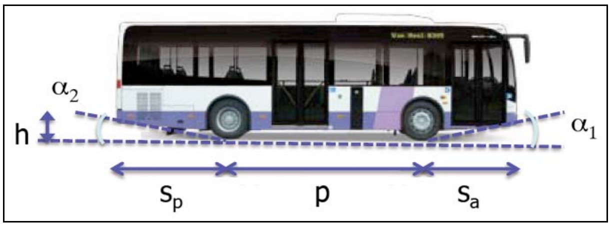

Figure 24: Maximum allowed slope

A second factor is the type of propulsion system used, and therefore the power required to overcome the motion resistances. As indicated in Figure 25 (Khanipour et al. 2007), if a path is winding, commercial speed is low and the engine is subjected to an anomalous and relevant effort.

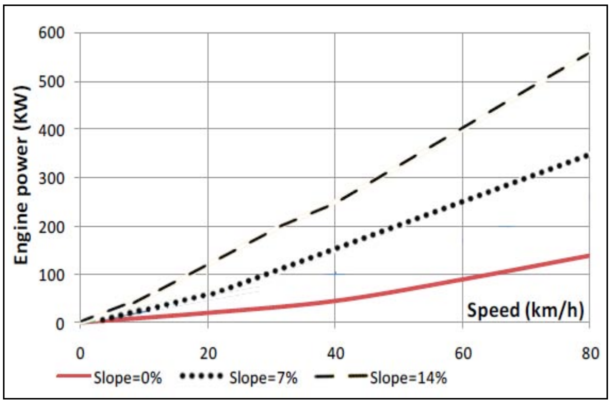

Figure 25: Required engine power vs speed and slope

A performance indicator relating to door numbers n and vehicle capacity w is the capacity per door c_d (spaces/door):

$$c_d = w / n \qquad (3)$$

A low value of c_d makes passenger boarding and alighting more comfortable. Table 3 indicates typical entrance factor ranges. The highest values were observed at double-decker vehicles.

Table 3: Vehicle capacity per door

vehicle type	c_d (sps/door)
Standard	22-34
Articulated	28-34
Double-articulated	38-40
Double-deck	38-76

The effects of number of doors on boarding and alighting times are shown in Table 4 (source: Kittelson and Associates 1999). Increasing from one to two doors reduces boarding time 40%, from 2.5 to 1.5 seconds per passenger. Similar reductions are given for front and rear alighting.

Table 4: Passenger service times (s/pass) for low-floor buses.

door channels	boarding	front alighting	rear alighting
1	2.0	2.8	1.6
2	1.2	1.5	0.9
3	0.9	1.3	0.7
4	0.7	0.9	0.5
6	0.5	0.6	0.4

4.7. Vehicle costs

Since different configurations of vehicle type, propulsion systems, guidance systems, on-board equipment are possible, the result is an extreme variability of costs. Table 4 provides an order of magnitude of purchase costs for different types of vehicles.

Table 4: Average vehicle purchase costs (€)

propulsion	standard	articulated	double-art.
Diesel	200,000	300,000	600,000
CNG	250,000	350,000	650,000
Hybrid	300,000	500,000	850,000
Trolley	400,000	650,000	1,000,000
Fuel Cell	> 1,000,000	-	-

Within a propulsion system category, vehicle costs can be related to its length. Figure 26 refers to internal combustion engine vehicles.

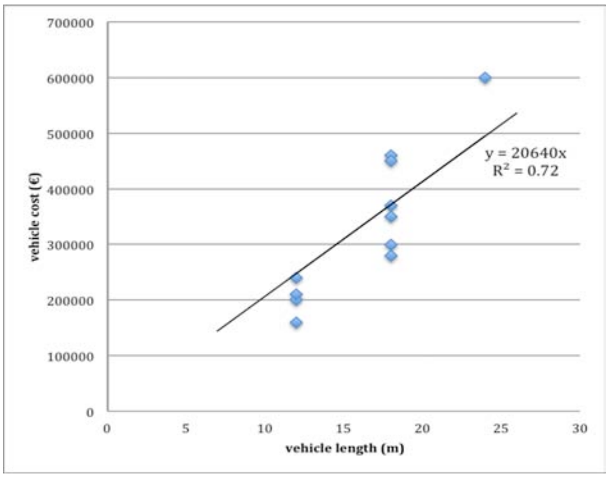

Figure 26: Vehicle cost vs vehicle length

A specific design of vehicle, can provide higher cost (+20÷50%). CNG articulated bus cost, for example, in Nantes city is 460.000 Euros.

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5. CONCLUSION

After a description of BHLS features and a review of experiences across europe, this paper focuses on the most widely used vehicles, in terms of external and internal layout, guidance and propulsion, ITS technologies and other on-board equipment.

The key factors that arise over traditional buses are identified. Plus, the paper introduces some performance models, mainly related to vehicles, line capacity and fuel consumptions. These models represent a starting point for the simulation of specific public transportation systems.

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