Bus with High Level of Service in Nantes, France: Characteristics and Results of the BusWay in Relation to Light-Rail Transit

Submission date (final manuscript): March 12, 2014

No. of words: 6,498

No. of tables: 3

No. of figures: 1

Total no. of equivalent words: 6,498 + 3×250 + 1×250 = 7,498

Authors:

Emilio Conles
Civil Engineer. Researcher.
Affiliation: Railways and Transportation Group, University of A Coruña
Address: ETS Ingenieros de Caminos, Canales y Puertos. Campus de Elviña, s/n. E-15071. A Coruña, Spain
Telephone: +(34)981167000 - ext. 5422
Fax: +(34)981167170
E-mail: econles@udc.es

Margarita Novales
Civil Engineer, PhD. Associate Professor.
Affiliation: Railways and Transportation Group, University of A Coruña
Address: ETS Ingenieros de Caminos, Canales y Puertos. Campus de Elviña, s/n. E-15071. A Coruña, Spain
Telephone: +(34)981167000 - ext. 1452
Fax: +(34)981167170
E-mail: mnovales@udc.es

Alfonso Orro
Civil Engineer, PhD. Associate Professor.
Affiliation: Railways and Transportation Group, University of A Coruña
Address: ETS Ingenieros de Caminos, Canales y Puertos. Campus de Elviña, s/n. E-15071. A Coruña, Spain
Telephone: +(34)981167000 - ext. 1450
Fax: +(34)981167170
E-mail: aorro@udc.es

Javier Anta
Civil Engineer. Researcher.
Affiliation: Railways and Transportation Group, University of A Coruña
Address: ETS Ingenieros de Caminos, Canales y Puertos. Campus de Elviña, s/n. E-15071. A Coruña, Spain
Telephone: +(34)981167000 - ext. 5414
Fax: +(34)981167170
E-mail: javier.anta.alvarez@udc.es

Corresponding author: Emilio Conles

ABSTRACT

This paper is intended to identify and analyze the reasons that have led the BusWay of Nantes (France) to be one of the most – if not the most – outstanding and successful cases of setting up of a BHLS system (Bus with High Level of Service) in European cities, inasmuch the lesson and conclusions extracted from its study may be applicable and useful to other sites experiencing similar conditions. This examination is approached from the point of view of both the measures implemented (infrastructures, vehicles, design of the transit service operations, complementary facilities and services, branding) and the results achieved (level of service in terms of frequencies and operating speed, reliability of the schedules, ridership, traffic safety). Furthermore, as BHLS and LRT (Light Rail Transit) are integrated within the same level of the trunk network in Nantes, this city provides a relatively level playing field to develop a comparison more equitable than usual of both systems. This comparative evaluation is addressed by this paper from the above-mentioned points of view.

As general conclusion, this paper shows, through the case study of Nantes, the suitability of the BHLS systems to meet demand volumes in the range from 1,000 to 2,500 passengers/h-direction at peak-hours with a level and quality of service very near the LRT, but with more moderate investment costs and higher flexibility.

1 INTRODUCTION: GENERAL BACKGROUND

The concept of Bus with High Level of Service (BHLS) refers to a new urban and metropolitan transit system with medium capacity, based on the use of buses, that assembles and merges a wide set of elements, equipments and measures intended to provide the bus-based transit modes with the necessary features to overcome the weaknesses and performance deficiencies that have characterized the conventional or common urban bus networks for the last three or four decades. BHLS must act consistently – i.e. with an integral, comprehensive and coherent approach – on a set of issues related to infrastructures, rolling stock, design of the transit service operations, complementary facilities, added passenger services and often also branding, with the aim of boosting the attractiveness of bus-based modes among the potential users. Accordingly, it is necessary that many of the advantages introduced by the new system are targeted at the areas of level of service (with frequency and operating speed as two major factors) and quality of service (with reliability indicators such as regularity or punctuality as significant parameters).

However, besides the primary goals (i.e. those related to the public transit supply), the deployment of a BHLS system often aims to catalyze the achievement of other derived objectives concerning issues such as urban refurbishment, emergence of new developments and/or other betterments in land use, environmental and social benefits, economic savings (in comparison to other medium-capacity transit systems), energy efficiency, and traffic safety. Therefore, in these fields BHLS can also be understood as a tool serving urban policies and strategic objectives that go beyond the scope of transit supply.

BHLS has been sometimes considered as the European adaptation of the Bus Rapid Transit (BRT) concept, which is broadly spread in North and South America, Asia and Australia. Although this idea is not fully incorrect, it requires some qualifications. Contrasted to “Full-BRT”, BHLS is usually very constrained by the dense structure of the European cities, so that it must pay more attention to getting a soft urban integration in order to facilitate a well-balanced share of street uses and to do not deter the utilization of alternative modes such as cycling and walking. This mixture of objectives often requires the employment of at-grade running ways such as bus-lanes or on-street busways instead of full grade-separated transit ways, sacrificing a bit the capacity and speed.

According to its features, BHLS must be considered as the bus-based alternative – or sometimes complement – to the type of Light Rail Transit (LRT) system that follows a similar soft approach in regard to urban insertion, is provided with an equivalent category of right-of-way and delivers more or less comparable transit capacities (which is referred to as “tramway” in Europe and hereinafter in this paper). Actually, the usual range of scheduled capacities for BHLS systems (from 1,000 up to 3,000 passengers/h-direction) is lower than the values that some tramway systems can reach (up to more than 6,000 passengers/h-direction). However, this limitation can be seen sometimes not as a crucial disadvantage but as a useful flexibility to fit, in an efficient way, those situations where a high level of transit service is required but the demand volume is not enough to justify the implementation of any LRT system (which is the case of many corridors in mid-sized European cities). Under these conditions BHLS has revealed – according to some studies (*1*, *2*) – as a more efficient transit solution than tramway in terms of overall system costs.

However, the blind preference towards the implementation of tramway systems instead of a properly substantiated selection has been a common fact in a wide number of European cities as a result of a notable degree of general unawareness about the BHLS’ capabilities. Nevertheless, an increasing amount of exceptions opting for the substantiated choice of BHLS systems has emerged in the last decade, with several French experiences leading this new movement. Thus, the city of Nantes (France) represents one of the most outstanding examples – probably the flagship – of how the key components and characteristics usually associated to tramway systems can be transferred and adapted to BHLS in order to meet somewhat lower demand volumes while preserving similar high-standards of level and quality of service. Because of its dimension, Nantes is also a good sample of mid-sized European metropolitan area. Consequently, this paper develops an in-depth study of the exemplary implementation of BHLS in Nantes as well as of its main results inasmuch its analysis may provide applicable measures and useful lessons to other sites with similar conditions.

An important factor is that, in Nantes, both tramway and BHLS are integrated within the same level of the public transit network (trunk or structuring lines), which makes this city a valuable framework for comparing them in a playing field leveler than usual. Thus, this comparison will be carried out in relation to several aspects such as: provision of infrastructures; vehicles and other auxiliary facilities and systems; operation parameters involved in the assessment of the level of service; reliability of the service in terms of regularity and punctuality; economic costs; ridership achievements; traffic safety; etc.

Furthermore, Nantes has been awarded by the European Commission as the European Green Capital 2013, with its sustainable transport policy and efficient public transit network being two major merits for this title. This award highlights the relevance of Nantes as a case study deserving a thorough analysis.

2 LOCAL BACKGROUND: THE NANTES METROPOLITAN AREA AND ITS TRANSIT NETWORK

The city of Nantes is located in the West of France. Its population amounts to 282,000 inhabitants in the central city (density: 4,326 inh./km^2), and its metropolitan area (24 municipalities composing the urban community of *Nantes Métropole*) reaches more than 582,000 inhabitants (density: 1,112 inh./km^2).

About 2,061,000 trips per day are carried out in the Nantes metropolitan area (*3*), with almost 16% of them being performed by means of public transit (*3*, *4*). The remaining modal split shows a share of 56% for cars, 24% for pedestrian trips and 4% for motorbikes and bicycles (*3*). The public transit network served a ridership of 121.3 million trips per year in 2012 (*4*) – with an average annual growth rate near 2.3% in the last five years – while the public transit use per capita amounted to 208 rides/inh.-yr.

The public transit network in the Nantes metropolitan area has been structured around three tramway lines that were successfully reintroduced from mid eighties onwards (lines 1, 2 and 3, which entered service in 1985, 1992 and 2000 respectively). These lines are arranged as cross-city routes that link different suburban or peripheral areas through the city center, where several interchange nodes are provided for transfers. Thus, these three tramway lines have made up the trunk network of the transit system, while they also boosted the urban refurbishment of the affected corridors.

However, early in the 2000s, the South-East corridor of the metropolitan area still lacked the setting up of a trunk line that was able to offer comparable level and quality of service and whose implementation could lead to a similar degree of urban betterment. According to these requirements, a new tramway line was suggested for consideration, but the preliminary demand studies forecast a ridership about 18,000 trips per day (*5*), which was judged insufficient to justify the expensive implementation of a tramway. Therefore, considering the balance between the required capacity and the investment costs as a major factor, the decision was to opt for a BHLS line which should be designed, to the extent feasible, by following a “tramway approach” in order to meet the performance requirements and high quality demands. Then, after two years of construction phase, the line 4 (which finally received also the brand name of “the BusWay”) was opened on November 6, 2006 and it completed the trunk or structuring level of the metropolitan public transit network (see Figure 1a).

Currently the total length of the four main lines amounts to 16.57 km for the line 1, 11.74 km for the line 2, 13.93 km for the line 3 and 6.95 km for the line 4 (which is clearly shorter than the three tramway lines).

The line 4 or BusWay connects the stations of *Foch-Cathédrale* (in the city center) and *Porte de Vertou* (in the outskirts, near the main ring road). The population covered within a distance of 400 m from/to the stops/stations amounts to about 26,000 inhabitants (*6*, *7*). This line runs through areas not as densely populated as the other three, which is a major factor explaining the lower forecasted demand and hence another reason for having discarded the implementation of a tramway line.

The setting up of the BusWay has been a public project promoted by the urban community of *Nantes Métropole*, with a strong political support. The operation and management of the BusWay is assigned to Semitan (the public-private company in charge of the urban and metropolitan public transportation in Nantes).

Besides the four main lines, the Semitan’s public transit network comprises more than 50 regular bus lines (after 2014 ten of them will be *Chronobus* lines, with upgraded services and improved performance), 4 express bus lines that operate only at peak hours on weekdays, a specific line for linking the central city and the airport, two water bus routes, a special service on request for persons with reduced mobility (PRM) and several night bus lines.

The public transit network is complemented with 39 parking lots for park-and-ride (P+R) – with an overall capacity for about 5,900 cars (*8*) – in order to facilitate co-modality between cars and public transit.

On another hand, with the aim of encouraging the use of bicycles as a transportation mode, more than 350 km of cyclable routes are provided in the Nantes metropolitan area.

3 THE BUSWAY'S INFRASTRUCTURES AND COMPLEMENTARY MEASURES

3.1 Running Ways

A key component for the full development of a BHLS system is the provision of at least a reserved or dedicated lane in as much extent as feasible, preferably with lateral separation by means of some sort of fixed physical element. Thus, the approach in this regard is that BHLS should benefit from a similar right-of-way category to the one that modern tramways usually have (category B, according to Vuchic's (*9*) classification). This kind of facility, in conjunction with prioritization systems at crossings, is a central tool for ensuring the performance and reliability of the transit system regardless the levels of traffic congestion.

In the case of the Nantes' BusWay (*10*), most of the whole round (86% of 13.9 km, including both directions) is provided with an at-grade dedicated right-of-way, while only 14% takes place on mixed lanes (flow shared with common traffics). Furthermore, most of the dedicated right-of-way (70% of the full round) is materialized in the form of median busway, whereas 14% of the whole route is carried out on lateral or curbside bus lanes and 2% on contra-flow bus lanes. According to the number of dedicated lanes in cross section, 79% of the full round is provided with double (two-ways) reserved lanes, and 7% with only one reserved lane (bi-directional, with alternate flows).

The core part of the dedicated right-of-way for the line 4 is the two-way median busway implemented along an arterial corridor (see Figure 1b). The physical lateral separation between the lanes for common traffic and the busway takes the form of a light level difference (step of 14 cm in general, although lowered to 6 or 7 cm in some stretches) finished with a curb, which is sufficient to prevent the unaware access of non-authorized vehicles. However, this separation of levels has to be removed in bridges, viaducts and crossings with other streets or roads. Both lanes of the busway are mostly separated by means of a green median strip, although this division is not applied to some sections because of the limited available width. As regards to the bus-lanes dimensions (*10*), its width ranges from 3.5 to 4.5 m in the sections with only one dedicated lane, while the two-way median busway has a total width ranging from an absolute minimum of 6.0 m to 7.5 m.

As a rule, the use of these dedicated lanes is exclusively reserved to the line 4, so they are shared neither with other bus lines (save a short stretch of conventional bus-lane near the city center) nor with taxicabs, bicycles, motorbikes, etc. In general, it is observed that car drivers respect the BusWay's right-of-way very strongly, similarly to as they do with the tramway lines. Moreover, crosswalks are not marked through the busway – they are located only at traffic lights – to preserve the priority of the line 4 in the same way as tramway.

As regards to the urban refurbishment, the insertion of the new running ways for the BusWay has served as backbone for the transformation of a former radial highway into a new boulevard (Figure 1b), whose integration of uses and urban landscape are much more suited to the desirable livability of the city. This conversion has implied that the amount of lanes available for general traffic has been reduced from two to one per direction in most of the avenue.

In conclusion, a significant effort has been made in Nantes for providing the line 4 with an adequate, efficient category B right-of-way. On the other hand, such right-of-way is usually regarded as an intrinsic and unquestionable feature of the modern tramway, which makes its general acceptance quite easier.

3.2 Intersections

The route of the BusWay has 26 at-grade crossings per direction (*10*), whereas there are not grade-separated intersections as neither overpasses nor tunnels have been specifically constructed for the line 4. Therefore, it is necessary to minimize the impact of these crossroads on the continuity of the buses flow. Accordingly, all these intersections are provided with automated systems that yield priority to transit vehicles. The buses are equipped with transponders that every time a bus approaches the intersection are identified by two loop detectors (located at different distances before the crossing). This detection activates the modification of the light cycle in the crossing in favor of bus priority, and subsequently, loop detectors installed after the intersection allow the traffic lights to resume its normal cycle. The disruption of the crosswise traffic lasts only for 15-20 seconds, as a bus takes about 12 seconds to fully cross the intersection (*11*).

The BusWay makes use of a special traffic lights signalization, alike to that used for tramways instead of general road signaling. Consequently, the employment of tramway signalization for a bus-based line has required a specific authorization from the French Department of Road and Traffic Safety. These measures allow the BusWay to benefit from the same transit priority that the tramway lines enjoy in Nantes.

Other particular feature of some intersections is the arrangement of special roundabouts that are crossed by the busway through their center. The rest of drivers lose the regular priority within these roundabouts, as their flow is controlled by means of traffic lights managed by the prioritization system. This type of roundabout, which is usual in tramway lines and also in some other French BHLS systems, has been introduced into 12 crossroads of the BusWay's route (*10*).

3.3 Stops/stations

A central idea in BHLS systems is that the traditional notion of bus stop should be superseded by the concept of station (or, more precisely, "ministations"), based on its fixed and non-displaceable location and on the high grade of useful equipments that are provided to the passengers.

The Nantes' BusWay has 15 stations along the line 4, which results in an average stops spacing of 496 m. This value is very similar to that found in the three tramway lines (502 m for the line 1, 489 m for line 2, and 449 m for line 3). All the BusWay's stations (except one of them) are disposed as lateral stations with opposite locations (that is, at both sides of the busway, without any center platform). Therefore, the boarding and alighting of passengers is performed at the right side of the vehicles (as usual in buses), but, by contrast, passengers are allowed to board and alight through any of the four doors of the vehicles in order to speed these processes (thus lowering the dwell times as much as possible). As drawback, the busway has not additional passing lanes in the station areas.

The standard dimensions for the BusWay's platforms have been set at 24 m long and at least 3 m wide, while their height above the pavement amounts to 27 cm (*10*, *11*). As the BusWay is not equipped with guidance systems, the stations have been located on straight sections, avoiding sharp changes in direction. This is intended to make the docking maneuver easier and to minimize the gaps between the platform and the vehicles floor (this is an important topic as concerns to the achievement of an easy, all-inclusive accessibility to the transit system). Anyway, as such gaps remain at about 5 cm (both in horizontal and vertical directions), the BusWay vehicles are equipped with deployable mini-ramps in at least one door in order to span the gap and thereby guaranteeing a proper accessibility.

The BusWay's stations are fitted out with a wide set of elements that boost the customer's convenience to a similar extent as tramway stations usually do. Besides ample shelters, these equipments include ticket vending machines (indispensable because the BusWay has a full off-board ticketing system), dynamic panels with real-time service information, voice information, lighting, maps of the transit network as well as CCTV surveillance in some of them for ensuring security. Furthermore, the BusWay's shelters have received a distinctive design which, along with static panels on the stop poles, contributes to endow the line 4 with a clear identification and a strong branding.

As regards to the urban environment, traffic calming measures have been implemented in the areas surrounding the stations, which have been treated as 30 km/h zones. Furthermore, the sidewalks and the stations' platforms in the median busway are linked by means of raised crosswalks trough the conventional traffic lanes, elevated 27 cm above the road pavement.

3.4 Other Supporting or Complementary Measures

A key factor for BHLS – like for any transit system – is, besides the effective integration into the transit network, the facility of potential customers to combine the use of public transit with private or individual vehicles (not only cars, but also motorbikes or bicycles) to complete door-to-door trips according to their particular needs or preferences.

As regards to the co-modality in relation to cars, a total of 6 P+R lots are linked to the line 4 in Nantes, which offer an overall capacity for 1,280 cars. This figure is not very different from the capacity offered by the tramway lines, as this amounts to 1,038 places in 5 P+R lots for the line 1, 990 places in 7 P+R lots for the line 2 and 1,805 places in 12 P+R lots for the line 3 (*8*).

On the other hand, the passengers' personal bicycles are not allowed on board the BusWay (they are admitted on board the tramway only at certain hours). However, a network of 54 bicycle parking stations

(*Véloparcs*) is available near the main transit facilities (bike-and-ride). Thus the line 4 is provided with 5 bicycle stations (34 places), which by now are fewer than those that tramway lines have: 9 bicycle stations (80 places) in the line 1, 8 bicycle stations (92 places) in the line 2, and 9 bicycle stations (68 places) for the line 3 (*12*). Furthermore, the subscribers to public transit have the possibility of using the *Cyclotan* service (a small foldable bicycle rented to subscribers which is allowed on all the Semitan's vehicles).

4 THE BUSWAY VEHICLES

The line 4 or BusWay is supplied with a specific fleet of 20 buses (*10*, *13*) based on the model Mercedes-Benz/EvoBus Citaro G. These are articulated buses, with an overall length of 17.94 m and a width of 2.55 m. Furthermore, they have been adapted to employ compressed natural gas (CNG) instead of diesel fuel (the use of CNG is a common feature of all the Semitan's buses in Nantes). This measure allows diminishing the local emissions of CO_2, NO_x and SO_2 without having caused significant detriments of the vehicles' reliability (the range of the BusWay vehicles with full tank reaches at least 400 km).

The BusWay vehicles (*10*, *11*, *13*) have 4 sliding doors for reducing the boarding and alighting periods and they are 100% low-floor (32 cm high above the pavement). The number of seats per bus can range from 37 to 42, with a total capacity in admissible comfort conditions (4 standees/m^2) about 112 passengers (note that the maximum capacity can reach 160 passengers, but this figure nears crowding conditions). This means that the capacity of a BusWay vehicle is around 47% of the average capacity that the tram units (streetcars) have in Nantes with equal occupancy density. In this regard, the trams fleet for the three lines includes 91 units (*5*, *14*, *15*): 46 Alsthom TFS (39.15 m long), 33 Adtranz/Bombardier Incentro (36.42 m long), and 12 CAF Urbos 3 (37.96 m long). These trams have a capacity around 240 passengers (4 standees/m^2).

All the BusWay fleet is integrated into an Automatic Vehicle Monitoring system (AVM) for improving fleet control and network management. The interior of the BusWay vehicles is equipped with displays that provide real-time information about the public transit services (next stop, waiting times for the next transfers, possible incidents in the normal course of the services, etc.) and cameras for CCTV surveillance. In compliance with the PRM's needs, each bus has two special places for wheelchairs near the second doorway, along with an automated mini-ramp at such door.

The driver is placed in a closed cabin, without interaction with the passengers. This configuration is possible thanks to the fully off-board fare collection system (tickets are not sold on board). This is another important measure for minimizing dwell times.

5 IDENTIFICATION AND BUSWAY BRANDING

The BHLS service has a brand name (BusWay) with its own logo, which identifies it as a distinctive product with respect to other bus services. But, simultaneously, the designation "line 4" (in continuation to tramway lines 1, 2 and 3) conveys the idea of inclusion into the topmost level of the transit network and thus the provision of a quality and level of service similar to the tramway.

The BusWay vehicles have a specific livery which, besides the stamp of the logo, allows a clear differentiation from the conventional urban buses. In the stations, the shelters have also a particular design and distinctive ornamental patterns, along with the identification by means of static panels and stop poles. As regards to the running ways, a strong color contrast is not necessary in most of the route as the clear identification of the busway derives from its grade of segregation.

In general terms, it can be concluded that the BHLS in Nantes has been provided with a strong identification and a valuable branding.

6 COSTS EVALUATION

The investment cost of all the necessary fixed elements (running ways, stations, priority systems at intersections, auxiliary systems such as ITS, complementary civil works, etc.) and the measures of urban refurbishment linked to the project amounted to a sum ranging from 52 M€ or 71.0 M$ (according to (*10*)) to 66 M€ or 90.1 M$ (according to (*5*)). These figures result in an average cost between 7.5 and 9.5 M€/km (from 10.2 to 13.0 M$/km). Anyway, this is much lower than the investment cost required for the extension of the tramway line 3 (4.1 km long), which totaled 24 M€/km or 32.8 M$/km (*1*), and considerably lower than the 12 M€/km (16.4 M$/km) that the extension of the tramway line 1 cost in 2000 (*5*).

As regards to the rolling stock, the procurement cost of each BusWay vehicle amounted to 460,000 € or 628,268 $ (*10*, *13*), whereas the purchase of the most recently acquired tram units for the Nantes' network amounted to around 2.25 M€ (3.07 M$) per vehicle (*16*). This large difference diminishes quite if the procurement cost is analyzed in terms relative to capacity: 4,107 €/place (5,609 $/place) for the BusWay and about 9,036 €/place (12,341 $/place) for the trams. Moreover, it should be taken into account that the service life of a tram (around 30 years) is much longer than for a bus (around 12 years).

On another hand, the operating cost of the BusWay vehicle amounts to 4.90 €/veh-km (6.69 $/veh-km) according to (*13*), although this figure would also include some costs concerning the regular maintenance of the dedicated lanes. Anyway, this value is lower than the vehicle-related operating cost estimated by Hodgson et al. (*2*) for a tram vehicle in a notional modeled case, which is calculated at 4.86 £/veh-km (5.87 €/veh-km or 8.01 $/veh-km).

An estimation of the life-cycle cost of the rolling stock has been applied to the above indicated figures (this process has additionally required some minor assumptions). The results show an annual cost per vehicle of 241,401 €/year (329,705 $/year) for the BusWay, and almost the double (480,664 €/year or 656,491 $/year) for the trams. However, the cost difference in terms of vehicle-kilometers travelled diminishes very significantly (5.89 €/veh-km or 8.04 $/veh-km for the BusWay; 7.91 €/veh-km or 10.80 $/veh-km for the trams). Finally, the influence of the much higher number of places makes the trams be slightly less expensive than the BusWay vehicles in relation to the vehicle capacity (annual cost of 2,155 €/place or 2,943 $/place for the BusWay versus 2,003 €/place or 2,736 $/place for the trams).

7 RESULTS OF THE BUSWAY: COMPARISON WITH THE TRAMWAY LINES

7.1 The Service Designed: Parameters Concerning Level of Service and Capacity

The transit service offered by the BusWay has been designed following a very similar approach to the three preceding tramway lines as concerns the main factors that affect the level of service provided to potential users. As detailed in Table 1, the daily service span and service frequency are configured in such a way that the BusWay users do not experience any significant disadvantage with respect to the passengers served by tramway lines (the headways in the line 4 are even a little shorter than in the line 3 and only a bit worse than in the line 1 for certain periods). Moreover, the operating speed offered by the BusWay according to the schedules is somewhat higher than that reached by any of the tramway lines (this fact may be related to the influence of a lower ridership on the boarding and alighting times). Nonetheless, some studies (*6*, *7*) have indicated for the BusWay an observed operating speed a bit slower than scheduled.

The scheduled capacity on the line 4 at peak-hours (3 min headways) reaches 2,240 passengers/h-direction in admissible comfort conditions (4 standees/m^2), whereas it would amount to approximately 4,800, 4,115 and 2,880 passengers/h-direction for the lines 1, 2 and 3, with the same standees density. Although the capacity offered is inferior for the BusWay than for the tramway lines, it is evident that it has been fitted according to the expected ridership.

7.2 Ridership

The annual ridership of the BusWay in absolute terms (data from (*17*) and (*4*)) is clearly lower than in the tramway lines, as shown in Table 2. However, this quantity, by itself and without contextualization, would be barely meaningful as it is affected by a lot of additional factors (for example, length of the routes, population and employment near the lines, number of stations, etc.).

A little more adequate approach is achieved if the ridership is analyzed in relation to some of the main infrastructural characteristics. Then it is observed that the utilization of the BusWay in terms of passengers per kilometer of line length and average passengers per station remains lower than for the three tramway lines (especially with respect to the line 1). Nevertheless, this kind of analysis reveals already that the relative differences are much less broad than when the ridership is examined only in absolute terms. A next step refers to the study of the ridership in relation to the total distance travelled by the vehicles operating in each line. This indicator, quantified in terms of passengers/veh-km, shows a relative behavior between lines rather similar to the two previous parameters. Finally, the occupancy rate relative to capacity should be considered in this case as the most meaningful utilization indicator, as it takes into account in a combined way not only the total travelled distances but also the capacity of the vehicles used in each line (i.e. the places-kilometer offered). Therefore, it considers the ridership in relation to the overall volume of the planned service. And in this regard, the figures reached by the line 4 surpass those of the tramway lines, which corroborates the successful of the BusWay in terms of ridership achievements.

7.3 Quality of Service: Regularity and Punctuality

The grade of compliance of the BusWay with the scheduled timetables is measured applying two different criteria according to the type of day: a regularity criterion is used for weekdays and Saturdays (shorter headways) whereas a punctuality criterion is applied to Sundays and bank holidays (longer headways). The regularity criterion states that the real interval observed between two consecutive buses in a stop should not exceed in more than 2 minutes the scheduled headway. On the other hand, the punctuality criterion establishes that a bus should depart from a stop within a maximum delay of 3 minutes and no more than 1 minute ahead with respect to the time scheduled in timetables.

Under these criteria, the regularity rate of the BusWay in 2008 reached 97.1% on weekdays and 97.3% on Saturdays (*6*, *10*). As the overall regularity of the trunk network (tramways and BusWay altogether) amounted to 95.1% in that year (*6*), this means that the regularity of the BusWay has been a little better than the average of the tramway lines. The compliance of the BusWay with the punctuality criterion lowers to 83.6% on Sundays and bank holidays, but this fact seems to be related to the higher severity of this criterion in operational scenarios characterized by large headways rather than to a real decrease of the BusWay's performance (*6, 10*).

7.4 Traffic Safety

As concerns to the levels of traffic safety related to the running of BusWay and tramways, the Table 3 – constructed by aggregation of data taken from (*17*) – reveals that the BusWay has experienced a rate of collisions (with other vehicles, pedestrians, bicycles, etc.) per distance travelled lower than any of the three tramway lines. Besides, the proportion of collisions that result in bodily injuries over the total amount of collisions is within a similar range to the tramway lines.

Thus, it can be concluded that the same high degree of safety to which tramway is usually associated has been achieved (or even surpassed) by the BusWay, so it seems that, in the case of Nantes, the absence of guidance systems has not significant negative effects on the running safety. Anyway, it is important to note that tramway lines run through the city center (where the pedestrian and cyclist density is higher), which may significantly influence their collisions rate.

8 CONCLUSIONS

The study developed in this paper has detailed the features and results that have led the Nantes' BusWay to be the most paradigmatic example of how a BHLS line should be implemented into a European city (in fact, the BusWay exceeds in several aspects the standards usually associated to the BHLS concept). The primary reason for the success of this implementation derives from the proper congruity between three planning stages:

- the diagnosis of the preexistent situation (the need for remedying the lack of a transit line with relatively high performance in the South-East corridor of the metropolitan area);
- the delimitation of ambitious but realistic objectives (to provide a level and quality of service, as well as a urban betterment, as similar as possible to those of the tramway lines, but avoiding the high investment costs that the insufficient demand would not be able to justify);
- and the choice of the most suited means to achieve such goals in a cost-efficient way (the selection and design of a BHLS line that adopts most of the strengths usually associated to modern tramway and adapts them to a bus-based system).

Following this approach, the measures transferred to the BusWay have included: a dedicated right-of-way (in the form of median busway); the installation of priority systems at every intersection (introducing centrally-crossed roundabouts in quite a few of them); the incorporation of stations (with a wide set of equipments that enhance the customers' experience) instead of simple stops; the integration of real-time information systems (both in stations and vehicles); the setting up of a fully off-board fare collection system; the use of vehicles with numerous doors allowing multiple boarding and alighting; the orientation of the line design towards inter and co-modality (including park-and-ride and bike-and-ride); the careful effort made to promote the BusWay brand and the clear identification of the line; the attention paid to the urban integration of the route and the development of urban refurbishment processes; etc. Furthermore, the attributes with which the BusWay has been provided have allowed the implementation of a transit service plan that follows also very similar parameters to that of the tramway lines in terms of service span, frequencies and operating speed (decisive factors for achieving a high level of service), although with smaller capacity in order to fit the lower expected demand.

On the contrary, only the existence of an automated guidance system and of an electric propulsion system are inherent tramway features that have been omitted in the BusWay (perhaps the former was considered unessential for bus-based systems in relation to its cost and the latter was replaced by the use of CNG, which improves flexibility and reduces a lot the investment cost with moderate emissions).

Moreover, all the suitable measures adopted in the scopes of infrastructures, vehicles, service design, branding and complementary services and facilities have been consistently combined from an integral, comprehensive and coherent approach, which makes up one of the additional strengths of the system (the so-called "holistic" approach). Thus, the mutual benefits of those measures have resulted in the outstanding success of the line in the areas of ridership (higher than expected, with an occupancy rate a bit better than in the tramway lines in terms of passengers/place-km), reliability of schedules (regularity and punctuality in the same range as tramway, or even slightly better) and traffic safety (fewer collisions in relation to the total distance travelled than in tramway lines).

Finally, as general conclusion, the case study of Nantes proves the suitability of those BHLS systems rightly implemented to meet demand volumes in the range from 1,000 to 2,500 passengers/h-direction at peak-hours with a level and quality of service very near the tramway, but with more moderate investment costs. Furthermore, in case of a future overload of the line, the BHLS allows the possibilities of increasing the vehicles capacity (by the use of 24-25 m long bi-articulated buses) or even, in the long term, the transformation into a tramway line reconditioning the busway path and thus avoiding a significant part of the construction costs that the establishment of a totally new line would imply. Therefore, BHLS can also be planned as an early step, more flexible and with lower investment risks, towards a possible long term implementation of a LRT system depending on the observed demand evolution.

ACKNOWLEDGEMENTS

This paper is part of the research project "Technological, economic and user collection comparison of new advances in medium-capacity transit systems", co-funded by the Spanish Ministry of Economy and Competitiveness and by the European Union through the European Regional Development Fund (ERDF).

REFERENCES

(*1*) Forschungsgesellschaft für Straßen- und Verkehrswesen (head: Deutsch, V.) *Hinweise zu Systemkosten von Busbahn und Straßenbahn bei Neueinführung*. FGSV Verlag, Cologne, 2008.

(*2*) Hodgson, P., S. Potter, J. Warren, and D. Gillingwater. Can bus really be the new tram? *Research in Transportation Economics*, Vol. 39, 2013, pp. 158-166.

(*3*) Nantes Métropole. *Évaluation du Plan de Déplacements Urbains 2000-2010*. Undated. Available at: http://www.nantesmetropole.fr/medias/fichier/fichier_1272879524780.pdf

(*4*) SEMITAN. *Chiffres clés*. https://www.tan.fr/jsp/fiche_pagelibre.jsp?CODE=18076193&LANGUE=0&RH=1229955912628 (Accessed July 2013).

(*5*) Laisney, F. *Atlas du Tramway dans les Villes Françaises*. Éditions Recherches, Paris, 2011.

(*6*) Oser, A. *Report of a BusWay visit. 3 days with the local authority Nantes Métropole and the operator Semitan*. COST Action TU-0603 - Buses with High Level of Service, 2009. Available at: http://www.uitp-bhls.eu/IMG/pdf/Report_of_a_Busway_visit_-_anglais.pdf

(*7*) Oser, A. *Travail technique pour site BHNS*. 2009. Available at: http://www.bhns.fr/IMG/pdf/Travail_Technique_Antoine_Oser_Pour_Site_BHNS.pdf

(*8*) SEMITAN. *39 parkings relais à votre disposition*. https://www.tan.fr/jsp/fiche_pagelibre.jsp?CODE=58205512&LANG.. (Accessed July 2013).

(*9*) Vuchic, V.R. *Urban Transit Systems and Technology*. John Wiley & Sons, 2007.

(*10*) Garrigue, D. *BHLS description: The BusWay - Nantes*. COST Action TU-0603 - Buses with High Level of Service, 2008. Available at: http://www.uitp-bhls.eu/IMG/pdf/Nantes_BusWay_Description_16juillet2009.pdf

(*11*) Garrigue, D., and R. Bélouard. *Nantes - Line 4 BusWay*. Pre-proceedings of the 23rd PIARRC World Road Congress, Paris, 2007. Available at: http://www.uitp-bhls.eu/IMG/pdf/literature_report_-_Busway_-_IP1-garrigue-E.pdf

(*12*) SEMITAN. *Les Vèloparcs, un nouveau service pour faciliter vos déplacements*. https://www.tan.fr/jsp/fiche_pagelibre.jsp?CODE=50266520&LANGUE=0 (Accessed July 2013).

(*13*) COST Action TU-0603. *Buses with High Level of Service. Fundamental characteristics and recommendations for decision-making and research. Results from 35 European cities. Final report*. Various editors, 2011. Available through: http://www.uitp.org/knowledge/projects-details.cfm?id=450#BHLS_EN_BOOK

(*14*) Lucas, S. Technique: Les matériels en service. *Les Tramways en France (Rail Passion, hors-série)*. Éditions La Vie du Rail, Paris Cedex, Nov. 2011.

(*15*) SEMITAN. *Le nouveau tramway de Nantes*. https://www.tan.fr/jsp/fiche_pagelibre.jsp?CODE=26144698&LANGUE=0&RH=ACCUEIL (Accessed July 2013).

(*16*) Revista Vía Libre. *CAF suministrará tranvías a las ciudades francesas de Besançon y Nantes*. Dec. 20, 2010. http://www.vialibre-ffe.com/noticias.asp?not=6444 (Accessed July 2013).

(*17*) SEMITAN and Nantes Métropole. *Bilan Accidentologie 2010 et programme d'actions*. September 2011.

LIST OF TABLES

LIST OF FIGURES

TABLE 1 Main Parameters of Transit Service Plan that Relate to the Resulting Level of Service in the Four Major Lines (Winter 2012-2013)

Issue	Parameter	Type of day	L-1 (tramway)	L-2 (tramway)	L-3 (tramway)	L-4 (BusWay)
Service span	Daily duration	Pink days [(a)]	21h 15min	20h 30min	20h 13min	20h 14min
		Green days [(b)]	23h 15min	22h 30min	22h 12min	22h 14min
		Blue days [(c)]	19h 45min	19h 06min	18h 37min	18h 26min
		Yellow days [(d)]	21h 15min	20h 30min	20h 11min	20h 14 min
Frequency	Headways (min)	Pink days [(a)]	Min: 3 Max: 30	Min: 3-4 Max: 30	Min: 5 Max: 30	Min: 3 Max: 30
		Green days [(b)]	Min: 3-4 Max: 30	Min: 5-7 Max: 30	Min: 6-7 Max: 30	Min: 5-7 Max: 30
		Blue days [(c)]	Min: 16 Max: 40-42	Min: 15 Max: 40	Min: 15 Max: 50	Min: 16 Max: 40
		Yellow days [(d)]	Min: 4-5 Max: 30	Min: 5-7 Max: 30	Min: 6-7 Max: 30	Min: 5 Max: 30
Operating speed	Travel length (km)	not applicable	15.0 [(e)]	11.74 [(f)]	13.93 [(g)]	6.95 [(h)]
	Travel time according to schedules (min)	Pink days [(a)]	Min: 39 Max: 43	Min: 36 Max: 42	Min: 39 Max: 46	Min: 15 Max: 19
		Green days [(b)]	Min: 36 Max: 43	Min: 36 Max: 37	Min: 39 Max: 45	Min: 15 Max: 18
		Blue days [(c)]	Min: 36 Max: 39	Min: 36 Max: 37	Min: 40 Max: 44	Min: 15 Max: 18
		Yellow days [(d)]	Min: 38 Max: 42	Min: 36 Max: 37	Min: 39 Max: 44	Min: 15 Max: 18
	Resulting operating speed (km/h)	Pink days [(a)]	Min: 20.9 Max: 23.1	Min: 16.8 Max: 19.6	Min: 18.2 Max: 21.4	Min: 21.9 Max: 27.8
		Green days [(b)]	Min: 20.9 Max: 25.0	Min: 19.0 Max: 19.6	Min: 18.6 Max: 21.4	Min: 23.2 Max: 27.8
		Blue days [(c)]	Min: 23.1 Max: 25.0	Min: 19.0 Max: 19.6	Min: 19.0 Max: 20.9	Min: 23.2 Max: 27.8
		Yellow days [(d)]	Min: 21.4 Max: 23.7	Min: 19.0 Max: 19.6	Min: 19.0 Max: 21.4	Min: 23.2 Max: 27.8

(a) “Pink” days are weekdays (from Monday to Friday) outside school holidays.
(b) “Green” days are Saturdays.
(c) “Blue” days are Sundays and bank holidays.
(d) “Yellow” days are weekdays (from Monday to Friday) during school holidays.
(e) Journey Ranzay ↔ François Mitterrand.
(f) Journey Gare de Pont Rousseau ↔ Orvault Grand Val.
(g) Journey Neustrie ↔ Marcel Paul.
(h) Journey Foch Cathédrale ↔ Porte de Vertou.

TABLE 2 Main Ridership Indicators in Absolute and Relative Terms for the Four Major Lines (2010)

Ridership indicator	**Measurement unit**	**L-1 (tramway)**	**L-2 (tramway)**	**L-3 (tramway)**	**L-4 (BusWay)**
Annual ridership	pax/yr	28,731,431	18,788,703	18,196,452	6,563,917
Maximal daily ridership in work day	pax/day	aprox. 110,000	aprox. 80,000	aprox. 72,000	aprox. 27,500
Ridership relative to the population resident in the service area	pax/inh.-yr	not available [(a)]	not available [(a)]	not available [(a)]	252.5 [(b)]
Ridership relative to the line length	pax/km(line)-yr	1,733,943	1,600,401	1,306,278	937,702
Average number of boardings and alightings per station	pax/station-yr	845,042	751,548	568,639	437,594
Occupancy rate relative to vehicle-kilometers travelled [(c)]	pax/veh-km	14.83	13.27	12.58	8.01
Occupancy rate relative to capacity	pax/place-km	aprox. 0.062	aprox. 0.055	aprox. 0.052	aprox. 0.072

(a) Some sources indicate that about 300,000 inhabitants reside at less than 700 m from a tramway stop/station. This figure would imply an average of 219 annual boarding per inhabitant for the three tramway lines altogether.

(b) This calculation has considered the population covered within a distance of 400 m from/to the BusWay stops/stations.

(c) Line 1: 1,936,862 veh-km; line 2: 1,415,988 veh-km; line 3: 1,446,548 veh-km; line 4: 819,448 veh-km (*17*).

TABLE 3 Main Indicators Related to Traffic Safety in the Four Major Lines (Aggregate Data from 2007 to 2010)

Traffic safety indicator	**Measurement unit**	**L-1 (tramway)**	**L-2 (tramway)**	**L-3 (tramway)**	**L-4 (BusWay)**
Total number of collisions (2007-2010)	not applicable	224	211	190	68
Number of collisions with bodily injuries (2007-2010)	not applicable	71	40	38	19
Collisions rate per 100,000 km travelled	coll./100,000 km	2.89	3.58	3.51	2.15
Rate of collisions with bodily injuries per 100,000 km travelled	coll./100,000 km	0.91	0.68	0.70	0.60
Rate collisions with bodily injuries / total collisions	%	31.7	19.0	20.0	27.9

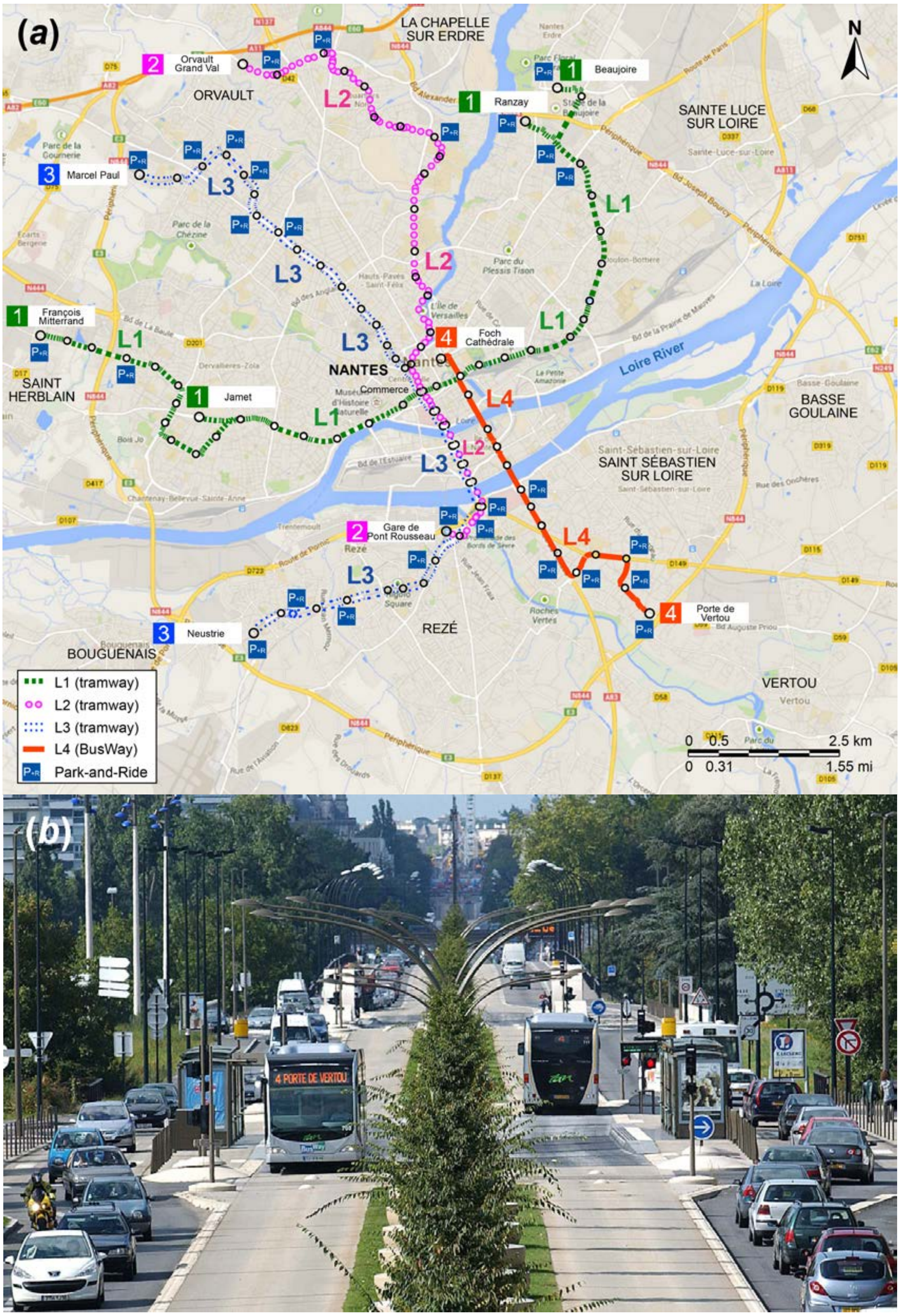

FIGURE 1 (*a*) General map of the four major lines in the metropolitan public transit network of Nantes; (*b*) The two-way median busway along a urban boulevard.

Sources: (*a*) Own work (background map from Google Maps); (*b*) COST Action TU-0603 - Buses with High Level of Service