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2.1

BRT STATE OF ART

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ACRONYMS

ADAS	Advanced Driver Assistance Systems
APC	Automatic passenger count
AVL	Automatic vehicle location
BEV	Battery electric vehicle
BHLS	Bus with a High Level of Service
BRT	Bus Rapid Transit
CCS	Combined Charging System
CINEA	Innovation and Networks Executive Agency
CNG	Compressed natural gas
DSO	Distribution system operator
FA	Financial Analysis
DoW	Description of Work
EBSF	European Bus System of the Future project
EC	European Commission
ESS	Energy Storage System
FA	Financial Analysis
FVA	Financial Viability Analysis
GPRS	General packet radio services
GPS	Global positioning system
GSM	Global System for Mobile Communications
GTFS	General Transit Feed Specifications
ICE	Internal combustion engine
IoT	Internet of things
ITS	Intelligent Transport Systems
Km/h	Kilometres per hour
KPI	Key Performance indicators
LCC	Life Cycle Cost
LRT	Light rail transit
MaaS	Mobility as a Service
MS	Milestone
MWh	Megawatt-hour
OCPP	Open Charge Point Protocol
PT	Public Transport
PTA	Public Transport Authority
PTO	Public Transport Operator

RTLS	Real time location tracking
SoC	State of Charge
SUMP	Sustainable urban mobility plan
TCO	Total Cost of Ownership
TSP	Transit signal priority
UC	Use Case
UG	User Group
UITP	International Union of Public Transport
V1G	Smart Charging
VAL	Véhicule Automatique Léger (automatic light vehicle)
VDV	Verband Deutscher Verkehrsunternehmen
WP	Work Package
ZEB	Zero Emission Bus

2 EXECUTIVE SUMMARY

This document is a deliverable of the eBRT2030 project, whose full name is European Bus Rapid Transit of 2030: electrified, automated, connected. The present report constitutes the deliverable 2.1 'BRT State of Art'. The following report refers to WP2 of the eBRT2030 project and specifically to the task 2.1, 'Characterisation of BRT systems today in Europe and experienced cities in other regions (BRT baseline)'.

The report describes the high-level bus rapid transit (BRT) system architecture and the status of the key areas of characterisation, from the interviewed cities and from systems outside Europe. BRT is a system, so it is necessary to define a reference functional architecture to identify its main functional elements. The report defines the BRT system concepts for the project, its benchmark and the characterisation process applied to the different functional elements. The document explores the European context for the implementation of BRT systems, as well as analyses the impact of electrification on BRTs. Furthermore, the report describes the state of the art of electric BRT technology and provides an overview of governance and planning for implementation of these systems.

This document serves as a first step in the development of the content and knowledge for the eBRT2030 project. It represents the baseline against which innovations will be developed, tested and evaluated, so to produce in WP9 the new concept for innovative European electric BRT systems.

3 INTRODUCTION

This document is a deliverable of the eBRT2030 project, whose full name is European Bus Rapid Transit of 2030: electrified, automated, connected. The present report constitutes the deliverable 2.1 'BRT State of Art'. The following report refers to WP2 of the eBRT2030 project and specifically to the task 2.1, 'Characterisation of BRT systems today in Europe and experienced cities in other regions (BRT baseline)'.

This report describes the high-level BRT system architecture and the status of the key areas of characterisation, from the interviewed cities and from systems outside Europe. The results of Task 2.1 will serve as inputs to the description and requirements identification related to the enablers of innovation for eBRT (Task 2.2), as well as in the definition of a global evaluation framework and models for assessing the impacts of such innovations (Task 2.3). Moreover, the results will also serve as inputs to the creation and verification of a reference eBRT system architecture covering e-buses, fleet and infrastructure innovations (Task 3.2); the integration of eBRT demos to the use case cities and infrastructure (Task 6.1); development of feasibility studies for follower and twinning cities for future EBRT systems (Task 8.1), and; in the creation of e-BRT concepts for all (Task 9.4).

The report describes the state of art of BRT systems today and aims at defining a characterisation for European BRT systems. This document will be the baseline against which innovations will be developed, tested and evaluated, so to produce in WP9 the new concept of innovative BRT 2.0.

This document has the following structure: the first part (Section 4) provides the definition of BRT for this report and presents an overview of BRT systems around the world and in Europe. The same section also defines the BRT system concept, the European characterisation of BRT, its electric component, and the potential impact of BRT systems. The second part (section 5) presents the State-of-the-art of the eBRT technology, considering the vehicles, infrastructure, and operations. The third part (Section 6) outlines the BRT concept for the eBRT2030 project, presenting the methodology used for the characterisation and benchmarking and the proposed scorecards. Section 7 presents an overview of the Demo cities in the project and the dynamic mapping developed in the framework of the task. Section 8 provides an overview of the governance success factors in the implementation of BRT systems. Finally, section 9 concludes the report with an outlook towards the European eBRT concept of the future.

ABOUT EBRT2030

The project European Bus Rapid Transit of 2030: electrified, automated, connected (eBRT2030) seeks to create a new generation of advance full electric, urban and peri-urban European Bus Rapid Transit (BRT) enhanced with novel automation and connectivity functionalities. The eBRT2030 project aims at supporting the next generation of innovative and effective public transport systems thus accelerating the transition towards zero emission road mobility across Europe and improving the life of European citizens.

The eBRT2030 project will demonstrate these innovative solutions in six European cities and one international city (Barcelona, Amsterdam, Eindhoven, Athens, Rimini, Prague, and Bogota). The project has also the ambition to carry out feasibility studies and small-scale demonstrations in South American and East Africa. This project has received funding from the Horizon Europe research and innovation programme under grant agreement No 101095882.

4 SETTING THE SCENE

4.1 DEFINITION OF BRT

BRT is the acronym of Bus Rapid Transit. There are many definitions in the literature, but for the purpose of the eBRT2030 project, this report will use the following definition of BRT system: ***a BRT line or corridor is a bus-based mode of transport that comprises performance-uplifting features that add to a high-capacity and performant bus-based system*.** Dedicated right-of-way, traffic signal priority, transit-oriented street design, off-board fare collection, all-door faster passenger boarding, and dedicated service branding are some of the key features that contribute to enhancing the quality and performance of a bus corridor, being any degree of deployment of these features beyond a certain benchmark[1] a valid stage of *BRTisation*.

However, it must be acknowledged that the regional context later discussed in this document plays a key role in defining the benchmark or minimum characteristics of BRT. Ignoring such element might yield to non-realistic thresholds when establishing a unified standard for characterising BRTs across the globe.

Many definitions for BRTs can be found in the literature, putting more or less emphasis on the flexibility of the final stage or ultimate definition. As an example, Cervero suggests the following definition: BRT is "a high-quality bus-based public transport system that delivers fast, comfortable and cost-effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service" (Cervero 2013).

This report, as first content deliverable of the eBRT2030 project, **attempts to provide the European lens and approach for characterising BRTs**. The approach used for this report will be reevaluated and revisited throughout the project lifetime building up towards the last content deliverable of the project (D9.3 – European e-BRT concept for all).

4.2 BRT AROUND THE GLOBE

The term BRT was first used as part of the 1937 Chicago Plan, which called for converting rail rapid transit lines into express bus operations on superhighways coupled with on-street distribution in downtown and central areas in Chicago, USA (Harrington et al., 1937 as quoted in Levinson et a., 2003). The upgrading of the busways in Curitiba, Brazil, towards a full-featured modern-day BRT system in the 1970s is often pointed out as a reference example that led to the eventual adoption of the concept globally. By the turn of the 21st century, already twenty-five cities globally had implemented BRT systems (Hidalgo, 2013). To date, BRT-type systems are operational in 187 cities around the world, carrying 34.5 million passengers every day, 58% of them located in Latin America or Asia and 25% in Europe. A third of BRT route kilometres and nearly two-thirds (63%) of ridership are in Latin America[2].

[1] In this context, the "benchmark" represents the established criteria or minimum requirements that must be met to consider a bus corridor as a BRT. Going beyond this standard by implementing additional features or achieving a higher level of deployment would signify a higher degree of BRTization.

[2] Data from https://brtdata.org/

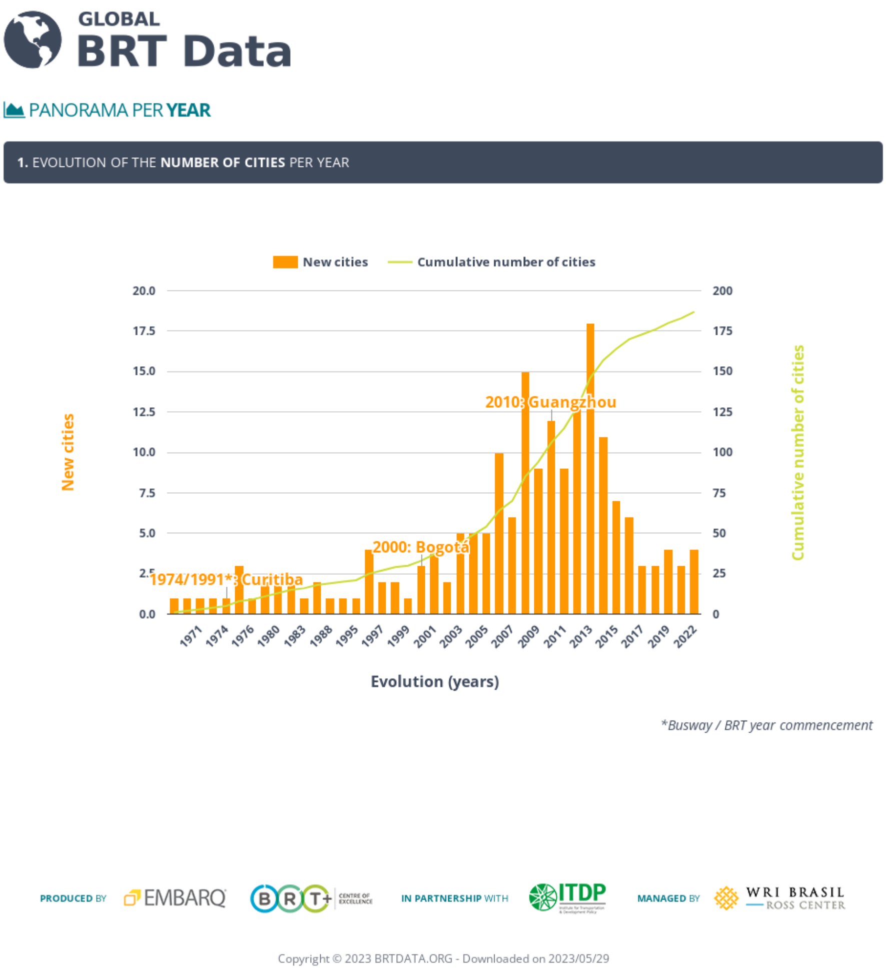

Figure 1. Number of Cities with BRT Systems per Year (Source: Global BRT Data)

The appearance and expansion of BRT in Latin America started during the economic and urban crisis of the 1970 and 1980s as an innovation that could transform cities and the way people move[3]. The first BRT in Latin America appeared in 1974 in Curitiba called *Rede Integrada de Transporte* (Ingvardson and Nielsen, 2017). It was the first Brazilian experience where the busways were preferred in the median position rather than curb side busways and since than more cities in Brazil and Latin America followed. The most well-renowned BRT system from Latin America is Transmilenio, which started operation at the end of the year 2000 in Bogotá, Colombia and provided a renewed boost to BRT image and high-impact mode not only in Latin America but also in the world. As of 2023, Bogotá's BRT comprises 12 lines (114 km total trunk line length) and carries an average of 39 million passengers per month at an

[3] Transforming cities with Bus Rapid Transit Systems, UITP, 2019. Available at: https://cms.uitp.org/wp/wp-content/uploads/2020/07/BRT_ENG_Web.pdf

average speed of 27 km/h (Transmilenio, 2023[4]). Nowadays, there are more than sixty cities in Latin America with operating BRT systems.

Figure 2. TransMilenio, Bogotá
© Scania

BRT systems have also been increasingly adopted in China and the rest of Asia in recent years. In 2004, Jakarta (Indonesia) introduced its first BRT system (also the first in Southeast Asia) – Transjakarta, which is now the world's longest BRT system in terms of total route length (Transjakarta, n.d.), and it counts already 30 battery-electric buses operating since the beginning of 2022 (Elective, 2022)[5]. In the same year, Seoul introduced its Metrobus system as part of the landmark 2004 public transport reform (SUSA, n.d.).

Other BRT systems soon followed, such as: Istanbul, Turkey (2007); Ahmedabad, India (2009); Guangzhou, China (2010); Yichang, China (2015); Peshawar, Pakistan (2020); Amman, Jordan (2021); the latter being an example of a policy shift giving priority to public transport and aiming at restoring a balance in the Urban Mobility System[6]. BRT systems are now found in at least 12 countries and 45 cities in Asia, carrying at least 2.9 billion passengers per year (Embarq, 2023). In, Amman, Jordan, the BRT comprises three routes for a total length of 32 km[7], while in Istanbul, Turkey, the 52-km long BRT

[4] https://www.transmilenio.gov.co/publicaciones/153489/estadisticas-de-oferta-y-demanda-del-sistema-integrado-de-transporte-publico-sitp-febrero-2023/
[5] https://www.electrive.com/2022/03/10/30-byd-electric-buses-hit-the-roads-in-jakarta/
[6] Transforming cities with Bus Rapid Transit Systems, UITP, 2019
[7] Transforming cities with Bus Rapid Transit Systems, UITP, 2019

system carries around 950 000 passengers per day, expanding along the European side of the city and crossing the Bosporus[8].

Figure 3. Xiamen elevated BRT © Andrey Samsonov

Because of its infrastructure-intensive concept, it is worth highlighting the elevated BRT in Xiamen (China), which opened in 2008 and with three corridors is considered the first elevated BRT network in China. The segregated BRT infrastructure design allows conversion to "heavy" metro and the integration with the existing metro system of Xiamen in the future, which is yet unseen in the world. Additionally, Xiamen´s BRT is also well known for its connection with biking infrastructure, designed as "cycle skyways" along the BRT corridors with the first 7 km already in service[9].

In Africa, Lagos (Nigeria) and Johannesburg (South Africa) were the first cities to implement BRT systems in 2008 and 2009, respectively (Hidalgo, 2013). In Lagos, the system offers high-capacity transit services running on designated traffic free lanes on the main corridor[10]. Cape Town (South Africa) soon followed in 2011, Pretoria in 2014, and Dar es Salaam (Tanzania) started in 2016. A new BRT project is expected to be completed in Dakar, Senegal in 2023[11].

BRT systems have also expanded to Northern America and Oceania. There are approximately 52 corridors in 22 cities in Canada and the United States altogether, and five corridors in seven cities in the Oceanic continent (World Resources Institute, 2023).

The Los Angeles BRT (J and G Lines) offers reliable, frequent transit service in LA County with bus speed improvements over local bus service, operational enhancements, and minimal infrastructure needs. The two lines run on dedicated lanes on the freeways and surface streets[12]. The J line opened in 2009 and the ridership has grown steadily since then[13].

In Europe, the first BRT system was introduced in the city of Runcorn, United Kingdom (UK) 1971 and consists of 22 kilometres, fully segregated busway[14]. Since then, eight BRT corridors have been inaugurated in seven cities in the UK, including Leigh-Salford-Manchester and Cambridgeshire, which connects peri-urban areas to suburban and rural areas to the city of Cambridge.

France is the country with more BRT systems in Europe with 33 corridors in 23 cities. A remarkable example is Busway Line 4 in Nantes (large metropole with 670 000 inhabitants). Originally planned and designed as a light rail line, BRT operations started in November 2006[15]. Since then, it has been an

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[8] Transforming cities with Bus Rapid Transit Systems, UITP, 2019
[9] https://archello.com/project/xiamen-bicycle-skyway
[10] Transforming cities with Bus Rapid Transit Systems, UITP, 2019
[11] https://www.cetud.sn/index.php/projets/brt-dakar
[12] https://www.metro.net/riding/guide/j-line/
[13] https://www.metro.net/about/brt/
[14] https://onlinepubs.trb.org/onlinepubs/tcrp/tcrp90v1_cs/Runcorn.pdf
[15] https://semitan.tan.fr/le-busway-a-la-nantaise

overwhelming success with a ridership that has tripled within 10 years to more than 42 000 passengers daily. Operated with 23 specific compressed natural gas (CNG) articulated buses, its infrastructure is 100% dedicated to performance with their own right-of-way lane and priority at all crossroads[16]. Following this success, a new line was launched in 2020 and now, Nantes BRT lines 4 and 5 are part of an integrated network of high capacity and high priority lines which combines light-rail and BRT lines adapting the transport mode to the capacity needs. Currently, there are more than 50 cities in Europe with BRT systems up and running. Other important examples include BRT systems in Utrecht, Netherlands; Granada, Spain; Stockholm, Sweden; and the Metromare system in Rimini, Italy, which stands out as the only trolleybus BRT in Europe.

Besides the above-mentioned examples, it is also important to present some of the European cases of BRT implementation covering a spectrum of different approaches, characteristics and time of implementation.

Pau, France, (160. 000 inhabitants) launched in 2019 the world's first hydrogen-powered BRT system. The innovative system serves 14 stations along a six-kilometre-long dedicated BRT lane with priority at crossroads[17]. Metz, with 125.000 inhabitants is another medium-size city in France usually referenced as a successful European BRT use case with two lines running on exclusive right-of-way for most of its 23 km in total, high capacity biarticulated vehicles and a strong branding. Building upon the success achieved, a third line is planned for 2025 to be fully operated with zero-emission fuel cell hydrogen buses running on green-hydrogen[18], that will make it the second hydrogen BRT in France.

Figure 4. Amsterdam line 300
© Manel Rivera Bennassar

In Amsterdam (agglomeration 1.654.000 inhabitants), the Netherlands, the BRT-line 300 connects one of the biggest suburbs of the Amsterdam, Bijlmer, via Amsterdam Schiphol Airport to Haarlem Central Station. The entire line, which is of the tangential type, is around 40 km long and runs on a completely segregated bus lane of 25 km. This BRT line was operated with articulated diesel buses and in 2021 these buses were replaced by new fully electric BRT buses[19].

More recent and remarkable examples can also be found in Spain. In 2022, Victoria Gasteiz inaugurated its first BRT system called BEI, fully operated with 12m and 18m articulated electric buses, replacing Internal combustion engine (ICE) buses within the busy 2a and 2b ring lines (Ayuntamiento de Victoria Gasteiz, n.d).

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[16] Transforming cities with Bus Rapid Transit Systems, UITP, 2019
[17] https://www.keolis.com/en/newsroom-en/press-releases/launch-of-the-world-s-first-100-hydrogen-brt-in-pau-in-the-south-of-france/
[18] https://www.eurometropolemetz.eu/a-la-une/nouvelle-ligne-mettis-c-3082.html
[19] ASSURED Innovation in e-Bus Rapid Transit, available at: https://assured-project.eu/storage/files/assured-innovation-for-bus-rapid-transit-public-version.pdf

With an initial fleet of ten e-buses, Madrid (Spain) introduced its first BRT in May 2023. The system has a total length of 31 kilometres, with 19 kilometres of physically segregated lanes and traffic light priority at crossings. The line is operated with a dedicated fleet of 12m electric buses and is branded as Bus Rapid (EMT Madrid, 2023).

In recent years, BRT systems worldwide have slowly but increasingly incorporated zero-emission buses within trunk lines. At the forefront is Guangzhou's BRT, that in 2018 replaced LPG with electric buses (UNEP, 2022). A more modest but not less ambitious example in Asia is Transjakarta that introduced its first 30 battery-electric buses within the system in 2022. The city's Public Transport Authority (PTA) is currently planning to incorporate a second batch of about 100 vehicles by the end of the year and moving towards its target of achieving a 100% zero-emission fleet by 2030 (Electrive, 2022). For its part, the Metrobus system in Mexico City has recently increased its articulated e-bus fleet to 60 units operating the first trunk line 100% electric in Latin America (Gobierno de la Ciudad de México, 2023). As for trolley buses, a remarkable case is San Francisco's first 3-km bus rapid transit line on Van Ness Avenue, inaugurated in April 2022 (SFMTA, 2022)[20].

In Brisbane, Australia, the new BRT will introduce a new fleet of 60 fully electric, high-capacity bi-articulated buses[21]. The BRT will be a key part of Brisbane's greater transport network connecting the city to the suburbs[22] and will run on dedicated busways to deliver more capacity, reliability, and quality than conventional street-running buses.

In Nairobi, Kenya, the new Bus Rapid Transit Line 3 will be the first dedicated electric bus rapid transit lane in East Africa. Conceived as electric, the system will also introduce intelligent transport system features and reasonably priced fare settings[23].

4.3 EUROPEAN AND ELECTRIC BRT

In the eBRT2030 project, the letter "E" stands for electric but also for European. This double reference of the "E" summarises and drives at the same time the innovations and developments that the project will carry out towards the efficient electrification of BRT services from the European context and needs.

4.3.1 EUROPEAN CHARACTERISATION OF BRT

European cities, particularly those with historical urban layouts, have often limited available space for dedicated BRT infrastructure inspired by the most infrastructure-intensive deployments derived from the Curitiba approach. This constraint poses challenges in designing and integrating BRT corridors within the existing urban landscape in the European context.

In general terms, **BRT developments in Europe are conceived to increase capacity in the existing network, improve quality of service (reliability, headway adherence) and/or efficiency in bus operations**. Although they may represent a unique opportunity to boost an entire bus network redesign, they do not play the same disruptive role seen in Latin America or more recently in Africa.

[20] https://www.sfmta.com/projects/van-ness-improvement-project
[21] https://www.brisbane.qld.gov.au/traffic-and-transport/public-transport/brisbane-metro/metros
[22] https://www.brisbane.qld.gov.au/traffic-and-transport/public-transport/brisbane-metro/about-brisbane-metro
[23] https://constructionreviewonline.com/biggest-projects/nairobi-bus-rapid-transport-brt-system-update/?utm_content=cmp-true

Furthermore, the **European scale of cities and its distribution is considerably different to other regions of the world.** The spatial distribution of cities varies considerably: Europe is generally characterised by a high number of relatively small cities and towns that are distributed in a polycentric fashion[24]; in contrast with other regions in the world where high proportions of the urban population is concentrated in fewer but larger cities. As an example, Paris and London — Europe´s largest cities — are less than one-third the size of Tokyo[25]. Over the course of this project, when working towards success and enabling factors for replication, an analysis of cities' sizes and the correlation with operational and design parameters will be performed and streamlined with the BRT bus market from the OEMs and industry perspective.

The difference in city scales is naturally transposed and reflected in the characteristics of the BRT systems in the different regions. While average daily ridership in the European BRT systems fluctuates between 20.000 and 35.000 boardings, flagship BRT systems in the world such as Transmilenio in Bogotá (Colombia), TransJakarta in Jakarta (Indonesia) and Metrobus in Istanbul (Turkey) carry around 2 million, 1.3 million and 1.0 million passengers a day respectively. Historically, many cities in Europe had or have tram and light rail systems in operation to serve the intermediate capacity part of the spectrum ranging typically around daily ridership of 30.000 to 50.000 passengers.

A classical capacity diagram (figure below) assists in placing the **role of BRTs in Europe in terms of corridor capacity within the traditional public transport modes.** Improved bus service operations through high-capacity vehicles and different degrees of right-of-way situate BRT capacity close to modern light rail transit (LRT) systems in single composition (30m-long tramways). Naturally, capacity thresholds are fluid and again very much dependent on the infrastructure and operational models, hence it is important to underline that this diagram is consistent with the European experience, but it is not necessarily exportable to other regions without adjustments.

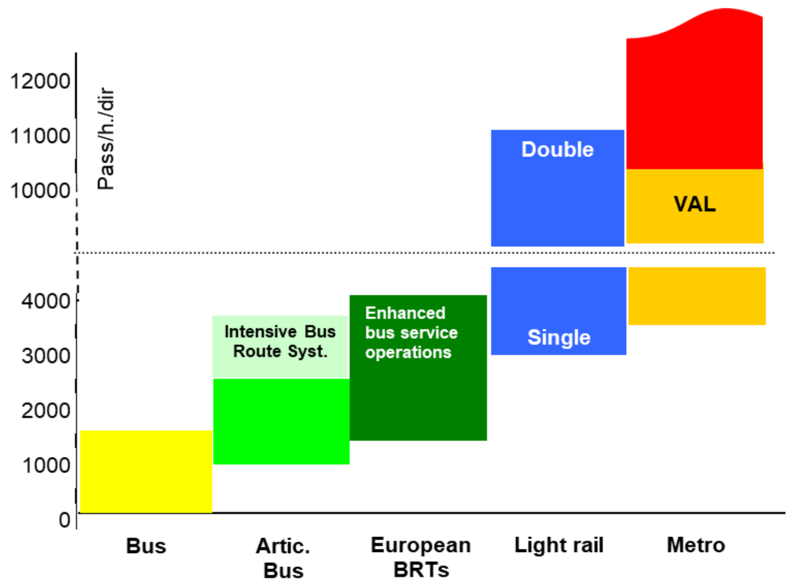

Figure 5. Modes' capacity chart (UITP)[26]

[24] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Urban_Europe_-_statistics_on_cities,_towns_and_suburbs_-_executive_summary&oldid=295044
[25] Ibid.
[26] VAL = Véhicule Automatique Léger or automatic light vehicle

It is also important to underline that a wide spectrum of sizes, typologies and requirements shapes a diverse array of BRT systems even within the European context. These elements influence and stretch the values shown in the figure above.

Essentially, the **BRT concept is associated with infrastructure and dedicated right-of-way**. Although a BRT system has many other components, public transport-oriented street design and priority measures are key enablers for performant mass rapid collective transport. In **Europe, the BRT systems on the higher end of the dedicated infrastructure spectrum share many design characteristics with modern tramways and light rail systems**. In this context, some BRT projects were implemented on the basis that they could be converted to tramways at a later stage, either when the demand would require it, or when the funding would become available. Some concrete examples of this approach are in Nantes, Amsterdam, or Lund where core elements of the BRT such as stations or running way pavement were constructed to tramway requirements from the outset to facilitate later conversion. As an example, Lund BRT opened in 2003 and was converted to light-rail 15 years later becoming one of the newest light-rail operations in Europe. In contrast, Nantes Busway Line 4 started operations in 2006 with articulated CNG buses and was upgraded to fully electric biarticulated bus operations also in 2020 to increase capacity on the line. BRT and LRT lines in Nantes follow similar design parameters and share the same layer in the public transport provision layer. Looping to the electric focus of BRTs, optimal electric-bus operation conditions are provided by tramway-oriented BRT design, such as the almost constant average driving speed with no stops at crossings, service regularity leading to uniform load distribution among vehicles and efficient driving skills (UITP, 2022).

The characteristic European urban population distribution leads to another dimension in BRT planning and operations which is the inter-local or peri-urban BRTs. Undoubtedly, the definition of BRTs needs to be again adapted to the European peri-urban and suburban landscape for which achieving the targeted bus service uplift requires a different approach in design and minimum requirements. This report acknowledges this particular element but does not include it in its current analysis. The **European peri-urban and suburban landscape will be analysed at a later stage of the project** and integrated into the vision for the European electric BRTs for 2030 and beyond.

4.3.2 ELECTRIC BRTS

4.3.2.1 EU Policy Framework

In Europe, climate change and air pollution are of major concern, and they are important factors in driving the transition towards clean and zero emission technologies in the transport sector (UITP, 2022). With its 'European Green Deal', the European Commission (EC) set ambitious objectives for no net emissions of greenhouse gases by 2050. Additionally, the European Commission has also adopted a set of proposals to make the EU's climate, energy, transport, and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels[27]. These proposals seek to modernise the EU's transport system focusing on sustainable urban mobility and facilitating different transport options towards an efficient and multimodal transport system[28].

[27] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
[28] Efficient and Green Mobility (europa.eu)

Overall, in Europe transport emissions represent 25% of the total greenhouse gas emissions and they have increased over recent years[29] and to achieve the aforementioned targets, transport emissions must decrease by 90% by 2050. Amongst the different applicable legal acts that constitute the wider EU policy framework for clean urban fleets, the revised **Clean Vehicles Directive promotes clean mobility solutions in public procurement tenders**, providing a solid boost to the demand and further deployment of low- and zero-emission vehicles. Concretely, the Clean Vehicles Directive imposes mandatory clean and zero emission bus procurement quotas in the European Member States in relation to their city bus fleets[30]. Other important elements in the EU policy framework include the European Commission **Clean Bus Deployment Initiative** (2017), the **Alternative Fuels Infrastructure Directive** and the **EC Urban Mobility Framework**. Finally, this year (2023), the European Commission proposed an amendment to the **CO2 emission performance standards for new heavy-duty vehicles** which would require all new urban buses to be zero-emission vehicles from 2030 (Article 3b).

In addition, according to the World Health Organization (WHO), loud, disruptive noise is a growing health problem with underestimated effects for citizens. A study carried out by the WHO showed that 30 per cent of people in Europe are disturbed by traffic noise[31]. Based on data reported in 2017 under the Environmental Noise Directive, it is estimated that at least 18 million people are highly affected and 5 million are highly sleep disturbed by long-term exposure to noise from transport in the EU[32].

Electrification of buses can play an important positive role in the cities (at low speeds, most of the noise comes from the engine), especially at bus stops and at city centres. This applies not only outside the bus, but also for users inside the vehicle. The differences in the Sound Pressure Level (SPL) for electrical and conventional technologies are very significant in the scenarios of stopped vehicles, accelerating and circulating at low speeds (< 30 km/h)[33], both inside and outside the units. On this topic, the EU's zero pollution action plan aims at reducing the share of people affected by noise from transport by 30% relative to 2017 levels by 2030[34].

4.3.2.2 Electrification

In recent years, the momentum for clean buses in EU-27 has been fostered through supporting policy and financing frameworks as well as various initiatives and projects and the commitment of European cities to decarbonise their bus fleet and public transport system. In this context, **electric buses have been increasingly seen as an effective solution and Europe saw a steady growth in the development, technology maturity and deployment of electric bus fleets** (UITP, 2022).

In the last five years, the number of electric buses in Europe significantly increased, with the number of new registrations that reached the record number of 4 152 (29,7% of the total share) in 2022, following years of steady growth (2 210 in 2020 and 3 282 in 2021)[35]. In 2021 for the first time as many

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[29] Transport and the Green Deal (europa.eu)
[30] Directive (EU) 2019/1161 of the European Parliament and of the Council of 20 June 2019 amending Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicle.
[31] https://www.volvobuses.com/en/news/2019/sep/electric-buses-can-address-noise-pollution.html
[32] https://www.eea.europa.eu/ims/health-impacts-of-exposure-to-1
[33] https://moves.gub.uy/en/electric-buses-reduce-noise-pollution/
[34] https://www.eea.europa.eu/ims/health-impacts-of-exposure-to-1
[35] Alternative Drivelines for City buses 2021 / 2022, W. Chatrou

as three European countries registered over 500 electric buses, with Germany leading the shortlist (555 units) followed by UK (540) and France (512).

While it is impossible to foresee the exact pace of adoption of electric buses in European cities, these numbers, together with the existing framework and commitments to decarbonisation of European cities are **the sign of the growing trend towards the increase electrification of bus fleets**. Therefore, when discussing a **vision for BRT systems in Europe for the year 2030, it is impossible to prescind from the electrification of these systems**.

Considering the qualities of BRT, improvements to such systems in Europe are necessary for attracting travellers and contributing towards a green and efficient transport system as required and fostered by the current policy framework. Electrified Bus Rapid Transit (eBRT) will be one of those solutions and will prove to be critical for reducing greenhouse gas emissions attributed to the transport sector, while making BRT systems more attractive to travellers in European countries.

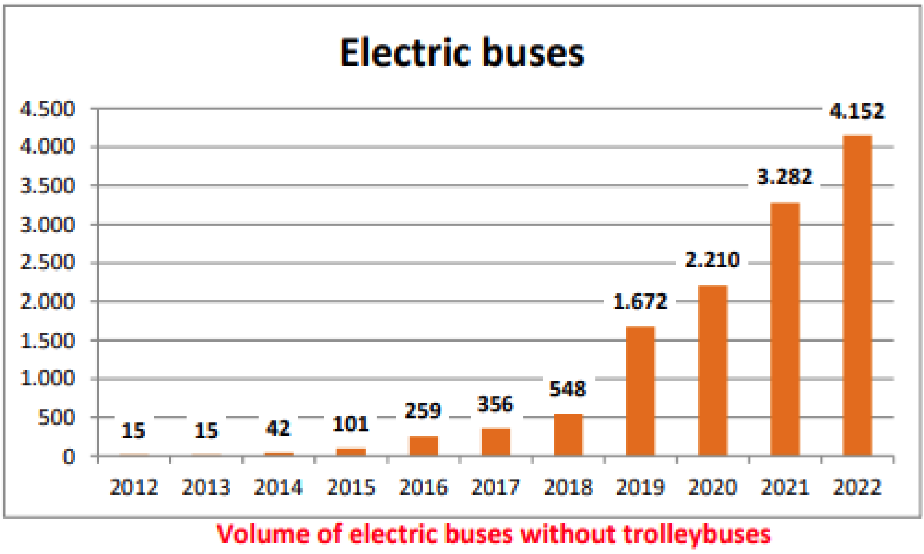

Figure 6. Volume of annual registrations, for years 2012-2019: Western-Europe + Poland / Years 2020-2022

Notes: EU27+UK+ICE+NO+CH - Source Chatrou Report 2023

BRT is recognised as one of the biggest innovations the bus domain has ever seen (UITP), being a mode with a high impact due to the positive transformative effects on cities in terms of reduction of congestion and air pollution, the ability to achieve quick gains at a reduced cost and rapid implementation (UITP, 2022).

'If electric buses are the natural step in the evolution of urban bus systems, autonomous, electric, bus rapid transit (BRT) is the ultimate step into the future, combining the best of the electric

technology (emissions-free, silent), BRT (segregated lanes, priority measures) and autonomous and connected driving (comfort, safety, efficiency)' (ASSURED[36] innovation in Bus Rapid Transit, 2022).

4.4 THE BRT SYSTEM CONCEPT

In conceptual terms **BRT systematically combines infrastructure, rolling stock equipment and operations to deliver improved service quality**. However, far from being isolated, the BRT system is part of the local bus network and interacts with the rest of the mobility environment in the urban area and impacts/is impacted by the "outside world". This was incorporated in the EU-funded project European Bus System of the Future (EBSF) aiming at improving the efficiency, sustainability, and attractiveness of urban bus systems under the term of 'Reference Architecture'. Overall, the logic of the EBSF Reference Architecture framed the role of public transport in the total mobility scheme.

Hence, the **reference architecture refers to understanding the bus-based enhanced service BRT within the broader bus system in the city and its integration with other public transport modes, combined mobility, and private transport**. It is crucial to grasp not only the functionality, requirements, and purpose of the BRT, but also to identify the interactions it has with other modes at all levels. This includes non-material aspects such as policy, planning, and regulations, as well as physical integration through street design and management, nodes (mobility hubs), and fare and information integration.

By understanding the specific functionality and goals of the upgraded bus service within the reference architecture, i.e., increased capacity, improved speed, or enhanced reliability…, it becomes possible to establish the requirements for the BRT system. These requirements encompass not only the physical infrastructure, such as dedicated bus lanes and stations, but also the technological aspects, such as zero-emission bus technology deployment, intelligent transportation systems and optimal operational plans. Moreover, the **reference architecture recognises that the integration of the BRT with other modes of transport is a key factor in ensuring seamless and efficient travel for passengers**. Therefore, it is crucial to highlight the need to consider interoperability with other public transportation modes, such as metro services or light rail, as well as the integration with soft transport modes like walking and cycling. This **holistic approach ensures that the reference architecture captures the intricate relationships amongst the BRT system, the broader transport network, and the city's mobility goals**, ultimately facilitating the development of an integrated and sustainable transportation solution.

The following concept and logic established in the EBSF project, the BRT system, as Bus System Solution, encompasses **three main components: vehicle, infrastructure, and operations**.

[36] The EU-funded ASSURED Project (fASt and Smart charging solutions for full size URban hEavy Duty applications) received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 769850.

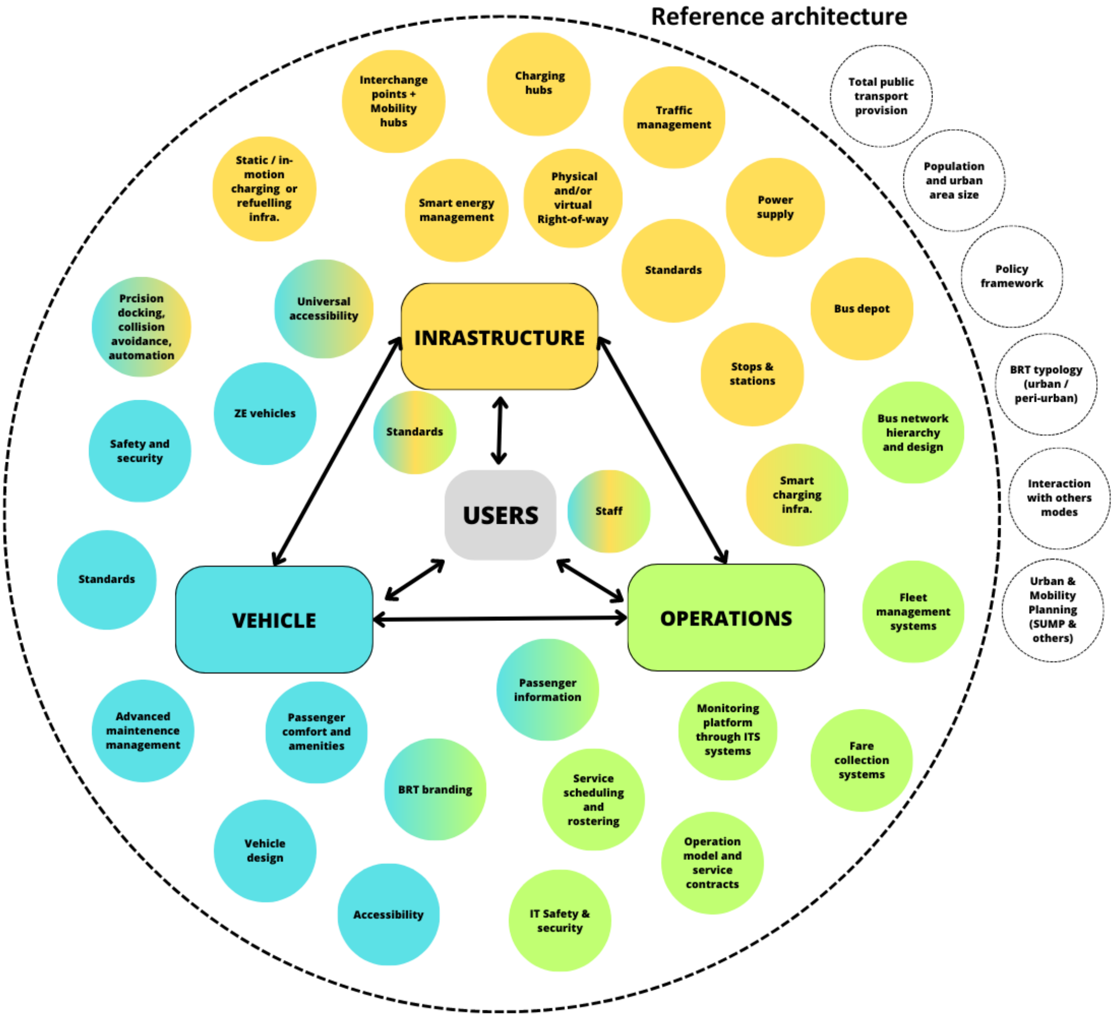

Figure 7. BRT system as BSS (Bus System Solution), the 3 main components surrounded by innovation and technology

Vehicle: The vehicle component of the bus system solution refers to the elements and features directly related to the buses used in the system. It encompasses the definition of the zero-emission vehicle design parameters to meet the specific requirements of a BRT service.

Infrastructure: The infrastructure of the eBRT system plays a fundamental role in supporting the operation and charging/refuelling needs of zero-emission buses. It encompasses various components such as enroute charging infrastructure, charging and maintenance facilities at depots, and enhanced stops along with physical or virtual right-of-way and bus-priority measures. The infrastructure component of the eBRT system solution also incorporates intelligent systems that optimise energy management, facilitate communication between system components, and enable advancements in assisted driving and automation. This comprehensive infrastructure framework ensures smooth operations and promotes the transition to a more sustainable and efficient eBRT system.

Operations: Efficient operations are essential for the success of an eBRT system. The operations involve aspects such as route planning, scheduling, real-time monitoring, smart energy management and more sustainable and efficient data-powered maintenance plans. Advanced technology systems provide operational control centres with real-time data on key parameters related to bus service provision (including vehicle state of charge and condition) and bus service usage. These systems enable operators to optimise schedules, manage bus deployment, and respond promptly to disruptions or incidents. Additionally, effective operations include training programs for drivers and maintenance personnel to ensure smooth operations and proper handling of zero-emission vehicles and BRT operations.

EBSF identified the Key Performance Indicators (KPIs) at system level looking at the operational level providing a way to measure performance and improvements on the bus system. The 5 core KPIs are:

- Capacity use rate (use versus offer ratio)
- Average Commercial Speed
- Cost per km/passenger
- Punctuality and regularity
- Global city transit emissions (modal share)

Capitalising on this legacy and with an eye on the innovation streams, this project will identify and define the KPIs to ensure the correct measurement and evaluation of the impact and objectives consecution.

4.4.1 ELECTRIC COMPONENT

As previously mentioned, the electrification of public transport is gaining momentum across Europe. This progress is essentially due to the contribution of heavy-duty vehicles including lorries, buses, and coaches to GHG emissions. In the EU, these vehicles account for **a quarter of GHG emissions from road transport** and over 6% of total GHG emissions.

In the Public Transport Sector, there is general consensus that electrification is the way forward to decarbonise the sector. **Electric buses also play an important role as they facilitate the acceptance of the implementation of BRT systems**. In fact, through the introduction of electric buses, public transport systems are gradually changing in the eyes of citizens the image of the bus as a pollutant intruder in cities. The **electrification of bus fleets is also an opportunity to rethink and optimise the public transport systems**, enhancing passengers' experience and making the bus more accessible and attractive.

In this context, it is important to highlight that the **introduction of battery-electric buses represents a paradigm shift for how operators understand their operations**, as dedicated charging infrastructure will be needed for the first time. Electric buses have a major impact on bus system planning and require a holistic approach to ensure a smooth transition from diesel or natural gas operations to zero-emission bus operation[37]. From a vehicle perspective, a system approach is now required; this needs

[37] Bus network planning from the operators' perspective (UITP 2022), available at Report-Bus-Network-planing-Oct22-web.pdf (uitp.org)

to include the service operation design together with the charging infrastructure and the vehicles. Furthermore, the fleet renewal needs to be considered as part of the energy transition plan together with many other different elements. This holistic approach is of particular importance for eBRT systems and given the complexity of the latter, it is critical to ensure full coordination between the key stakeholders involved in the process from early stage: the municipality, the operator or operators, vehicle manufacturers, technology providers, communication and outreach agency, construction companies if infrastructure changes are involved etc[38].

As part of the eBRT2030 project, electrification will be a key component of the six demonstrations that will introduce novel functionalities in order to improve the charging infrastructure, and alleviating grid congestion. On the other hand, some concerns still remain for operators and authorities regarding the transition to electric fleets, and these include:

- Insufficient experience and internal capacity to roll out electrification, charging infrastructure, engage in procurement for buses and charging, etc.
- Choosing and deploying the adapted charging systems (opportunity and/or destination).
- Coordinating responsibilities between different stakeholders (land, charging and vehicle ownership, general management, financing, etc.) and bringing together all the necessary actors.
- Ensuring the successful operation of electric public transport fleets, particularly in cities or regions with little to no previous experience.
- Getting a sufficient connection to the grid and managing the impact of charging on the grid.

4.5 IMPACT OF BRTS

Investment in transportation may have implications in a variety of dimensions, such as the modal share, road safety, spatial distribution of population, wages, and trade and the composition of industry. BRT has the potential of having a great transformative effect on cities but is important to underline that **the impact depends on the local conditions and how the methodology is used for measurement purposes**[39].

When looking at the general features of BRT systems in different geographical areas (Africa, Asia, Europe, Oceania, South America and USA-Canada), it is possible to observe that the BRT systems in North America and Oceania have the fastest BRT systems, but they have less kilometres of lanes, less stations and higher distance between stations (see Table 1 below). On the other hand, the Asian and Latin American systems have widely developed their transportation systems with higher number of stations, kilometres of exclusive lanes and passengers per day. The European BRT systems, as for their general features, seem to stand between these two models. The table below tries to provide a glimpse on the general features of BRT systems divided by continent.

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[38] Bus network planning from the operators' perspective (UITP 2022)

[39] Transforming cities with Bus Rapid Transit Systems, UITP, 2019

Table 1. General features of BRT systems per continent

FEATURE	AFRICA	LATIN AMERICA	ASIA	NORTHERN AMERICA	EUROPE	OCEANIA
Number of cities	6	45	46	63	22	5
Length of exclusive lanes (km)	152	2,003	1,691	744	919	109
Total number of stations	143	3066	1934	867	1135	114
Average number of stations within a line	18	16	23	20	23	12.6
Average distance between stations (m)	995	653	890	1,005	656	1758
Trips per day	491,578	20,785,206	9,238,060	1,005,796	2,914,113	436,200
Average fare price ($)	0.99	0.63	0.49	2.33	2.3	3.77
Operating speed (km/h)	30	22.08	23,48	28.37	23.27	37.42
Infrastructure cost (M$/km)	7.83	12.65	17.78	8.75	11.53	56.17

Own compilation; Source: (Embarq 2023)

However, conditions in different cities can be quite diverse: the dependence on car can vary substantially as well as the sustainable transport network depending on past development and characteristics such as metropolitan structures, density, land use, public policy, and income[40].

This section presents some of the potential impacts of BRTs worldwide and in Europe. It is necessary to underline that most studies that examined the impact of BRTs had a regional focus outside Europe, namely on cities in Latin America and Asia. In these two continents BRT systems had a longer trajectory and predominance, and therefore mid and long-term impacts can be already assessed. It is also important to specify that these cities' social, environmental, geographic, institutional, and economic conditions significantly differ from their European counterparts. Hence, the review presented below should be taken only as snapshot of the potential impact of BRT systems on cities on different levels and it does not have the ambition to provide a comprehensive overview or an assessment necessarily applicable to Europe. The section tries to include a few European examples alongside worldwide cases, but a more comprehensive, and easily accessible research is needed to determine mensurable positive impact of European BRTs.

Increased ridership and reduced travel time

One of the most significant impacts of BRT systems is the **increase in ridership and the reduction of travel time**. The largest travel time reduction and increase in ridership have been observed in cities where the BRT line was segregated from other traffic, for instance in the middle of a large road, and

[40] Transforming cities with Bus Rapid Transit Systems, UITP, 2019

where operations were frequent, thus reducing waiting times (Ingvardson and Nielsen, 2017). The table below presents the increase in ridership observed in some BRT systems.

Table 2. Increased ridership in some BRT systems

CITY: NAME OF BRT SYSTEM	INCREASE OF RIDERSHIP AND/OR REDUCED TRAVEL TIME
Paris: Trans-Val-de-Marne	134% in ridership after opening due to 16 minutes decrease in travel time along the 20 km corridor.
Dublin: Quality Bus Corridors	125% for the northeastern Malahide corridor and 63% for the southern Stillorgan corridor
Madrid: Bus-VAO system	reduced travel time in 33%, ridership increased by 85%
Brisbane, Australia	Ridership increased by 56% due to a fully segregated system with signal priority and high frequency, resulting in a 70% travel time reduction
Liverpool: Parramatta Transitway in Sydney	51% travel time reduction and 56% ridership increase
Cleveland Euclid corridor BRT, USA	60% ridership increase after two years of operation due to a largely segregated system, ensuring a 34% speed increase.
Honolulu, Hawaii	49% travel time reduction resulted in a 59% ridership increase after one year of service
Miami: South Miami-Dade Busway	50% increase in ridership resulting from a travel time reduction of less than 10%
Instanbul Metrobüs	Carried passengers increased from 110,000 to 240,000 passengers per day

Source: (Ingvardson and Nielsen, 2017; Alpkokin and Ergun 2012)

In one of the cases partially applicable to Europe, the construction of the Istanbul Metrobüs, launched in 2008, contained three main items: the BRT infrastructure; a re-organisation of public transportation and intermediate forms of public transportation lines; and the improvement of the highway. The removal of conventional bus and intermediate forms of public transportation lines further avoided vehicular chaos around the bus stops and arbitrary stops of such minibuses at restricted areas. This led to the removal of around 1530 vehicles of intermediate forms of public transportation, partly or fully using the Metrobüs corridor. Most of them shifted to the re-organised lines that serve as feeder routes. In other words, the reorganisation of unnecessarily long and parallel lines along the European side section of the corridor reduced the buses vehicle-km for 1000 passengers from 517 km to 190 km (Alpkokin and Ergun 2012).

Figure 8. Metrobüs corridor views
(Source: Alpkokin and Ergun 2012)

Other important examples are Leeds *Guided Bus Service* that attracted between 10% and 20% of new passengers from people using cars (Bain & Tebb, 2002), and Dublin, where around 16% of the new trips on the *Quality Bus Corridor* originated from former cars' users (Rambaud and Cristóbal-Pinto 2009).

Reduction of CO2 emissions

BRT systems, even when fully or partially operated with ICE vehicles, have been able to achieve a significant CO2 emission reduction within transport systems due to modal shifts, particularly from traditional bus systems. Another reason of this important result it is BRT's capacity to transport more passengers in a fastest way, resulting in less fuel consumption and thus less GHG emissions from the operation. Relevant evidence can be drawn from Guangzhou BRT, where a post-implementation analysis reported a reduction of 84 000 tons of CO2 annually. A much larger reduction of roughly 249 000 tons of CO2 is expected when the ongoing replacement of ICE with electric vehicles will be completed (UNEP,2022).

The Istanbul Metrobüs has reduced vehicle-km due the removal and re-organisation of the conventional buses saving up to 125 tons of CO2/day, while the removal and re-organisation of the intermediate forms of public transportation amounts to 42 ton of CO2/day (Alpkokin and Ergun 2012).

Road safety

Road safety is another element where BRT systems have the potential of playing an important role. BRTs in Latin America and India contributed to a 52% drop in fatalities and a 39% drop in injuries, controlling for citywide accident trends. Better street and crossing design, dedicated pedestrian and bicycle infrastructure and improved driver behaviour due to the elimination of on-street competition for passengers are the main elements to explain this decrease (Venter et al. 2018).

The Metrobüs of Istanbul had also a positive impact on accident reduction. The statistics of the Istanbul Public Transportation Authority showed that an accident occurs every day on the conventional bus network. With Metrobüs, this has been substantially reduced and only five accidents (without injury) were recorded in 2010 (two were caused by the vehicles in the mixed traffic lane). However, safety problems still exist arising from the design limitation of maintaining the number of lanes along the corridor which caused also these two accidents (Alpkokin and Ergun 2012).

Impacts on integrated mobility

Although consistent and quantifiable data is still not available, some empirical evidence has shown the benefits of **integrating BRT systems with other sustainable modes of transport** – non-motorised modes in particular– to encourage intermodality and provide seamless solutions for the so-called "last mile" trips. A remarkable example can be found in Guangzhou, where the development of the trunk BRT system corridors provided the opportunity to introduce more than 20km of high-capacity, physically segregated cycle infrastructure, improved sidewalks, and a bike-sharing system with 113 stations and over 5000 bicycles (ITDP, 2011 and UNEP, 2022).

Figure 9. Safe, high-quality walking and bicycling spaces along Guangzhou BRT corridor
Source: ITDP

Bogota followed a similar, more strategic approach in additional enhancements and expansions of its BRT system. To support the uptake of utilitarian cycling, Bogota has been increasingly incorporating bike-lane corridors along trunk lines and provided roughly 6 000 parking spots in safe and monitored bike parking facilities around more than 20 BRT stations[41] (Bogota mobility Secretary, n.d.). Last year, the city inaugurated its long-awaited bike-sharing system comprised of 5000 bicycles and 113 stations strategically located to facilitate connection with the BRT system[42] (Bogota's Mayor office, n.d.).

Figure 10. Cycle parking facility at Portal Américas Station, Bogotá

Source: TransMilenio

Impacts on urban development and accessibility

With regards to impacts on urban development, **public transit systems produce positive effects if they are part of a larger project of urban planning**. Best examples of urban development in corridors served by buses are Curitiba and Ottawa, where urban development concentrated along the bus lines (Ingvardson and Nielsen, 2017).

In Boston, properties near the BRT line densified after the implementation of the Silver Line BRT. The total amount of money put into urban development accounts for $600 million USD. Other BRT systems

[41] https://www.movilidadbogota.gov.co/web/cicloparqueaderos
[42] https://bogota.gov.co/bicicletas-compartidas

did not obtain the same effects. In Adelaide, no evidence of increased urban development was observed in relation to the O-Bahn system (Ingvardson and Nielsen, 2017).

In terms of the relationship with increased land values and increased accessibility along the BRT corridor, Istanbul Metrobüs is different, because the first three phases were implemented along a densely urbanised corridor where it is difficult to expect more land intensification even in the long term. In terms of accessibility, the BRT corridor serves a population of more than 1.1 million. The average trip duration on the Metrobüs network is 40 min compared with 90 min before Metrobüs. The accessibility impacts extend further than the population along the corridor mainly on the European side, as it provides the only fast means of transport across this major water barrier and severe transportation bottleneck between both sides of the city where 36% of the population resides on the Asian side and the rest on the European side (Alpkokin and Ergun 2012).

In Nantes, a survey conducted with public transport users for evaluating the Chronobus BRT service revealed that 45% of the sample considered its proximity as a crucial factor in dwelling location (Delsaut & Rabuel, 2016). The survey also indicated that the Chronobus program resulted in overall positive views (users and non-users alike) regarding the improvements in the urban areas affected.

It is nonetheless difficult to find concrete information on the effects of BRTs in urban revitalisation development but scattered empirical information may prove such correlation. The introduction of Nantes line 4 BRT presumably triggered the development of vacant or subtilised land as it is illustrated by the multiplicity of newly built, mid-dense residential building along the corridor. Similar trends have been also reported in Glasgow where the introduction of the Clyde Fastlink BRT spurred an urban renewal, namely hotels, recreational and educational facilities, and mid-dense residential buildings[43].

While regional differences need to be considered when comparing cities, it seems that BRT might be a catalyst for urban redevelopment. This effect has to be carefully addressed and regulated due to the well know counteractive negative effect that urban enhancements, i.e., public transport corridors, parks, and pedestrian areas, in driving gentrification due to rising housing prices or rents.

Social impacts

BRTs might also be considered as a mobility system that can support **social equity.** Existing literature and parts of this report presented some of the direct impacts of BRT systems (i.e., travel time reduction, travel cost and accident cost). Regarding the social impacts of BRT systems in Europe, evidence is still very limited (to the authors' knowledge).

On this aspect, the COST report, examining 35 BRT systems across Europe (COST - European Cooperation in Science and Technology, 2011), drew some interesting observations:

- Increasing patronage and significant travel time gains in all the European BRT systems analysed.
- BRT corridors integrated in the bus network enhances the public transport service supply across the city, even in hilly areas or intricated street layout. Open BRT systems such as Lorient or Gothenburg allow buses to join the BRT infrastructure in parts of the route offering fast one-seat rides usually between the outskirts and the city centre.

[43] https://www.transport.gov.scot/media/48593/bus-priority-case-studies.pdf

- Step-free access on BRT vehicles from stations positively impact the accessibility of the network and decrease commercial speed through quicker boarding and alighting.
- Fare-integration of BRT services and the rest of the public transport provision impact positively in acceptance and patronage of the “premium” services.
- BRT systems observed significant ridership gains compared to pre-BRT services arraying between 15 to 150%, contributing to achieve social and quality of life objectives.
- Usually, BRT infrastructure deployment yields to significant improvements in the quality of public space when the bus-priority infrastructure is integrated with street and urban redesign withing a larger scope, as was the case for 54% of the European BRTs assessed.

Despite the observations outlined above, the COST report identifies the lack of evidence on the BRT impacts on social factors, possible attributed to the fact that most of European Union Finance Ministries have imposed thresholds for pre- and post-implementation appraisal, with full socio-economic appraisal mandatory only for projects above a certain threshold (thresholds varying from € 50 – 100 million) and BRT schemes not exceeding it[44]. Some interesting, quantified results are, nonetheless, provided for worldwide cases and are briefly presented below.

There is substantial evidence that BRTs can deliver significant **savings in average passenger travel times** (i.e., savings up to 52 min per day and 59 min per peak period for Istanbul and Jakarta respectively) (Venter, Jennings, Hidalgo, & Pineda, 2018). From an equity perspective, the question is how these are distributed across users: Bogota’s system is considered to have produced more travel time savings for the poor (18 minutes per trip), than for the middle-class (10 minutes) (Cervero, 2013), while in Lima, Peru, it has been estimated that the population belonging to lower sociodemographic groups may benefit from an over 23% of reduction in travel time (Oviedo, Scholl, Innao, & Pedraza, 2019). When compared to private car travel time and the redistribution of public space in favour of BRT (converting car laned into BRT lanes), as low-income population is more likely to be public transport users, the equity impact of BRT may be even larger (Venter, Jennings, Hidalgo, & Pineda, 2018).

Going one step further, the level to which the unprivileged population can benefit from making those trips (i.e., for better job opportunities) is still set under research questions. Studies in Bogota and Cali show the BRT potential to **improve access of the poor to low-skill job opportunities** (Cervero, 2013), but results may be highly variable across systems, depending on the location of the system in relation to the residential location of the low-income communities. If we exclude the equity element from our equation, though, there are no arguments against the positive impacts of BRT systems on the **accessibility** (either accessibility of the BRT system itself, or accessibility to destinations via the BRT) across the urban space they represent.

In Nantes, the survey by Delsaut & Rabuel (2016) showed that respondents from specific areas perceived greater abilities to access the rest of the city, amenities, and jobs with the implementation of the Chronobus program. The program, as part of a wider urban renewal program, seems to have produced positive social impacts, particularly in the disadvantaged areas (Delsaut & Sebastien, 2016).

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[44] COST - European Cooperation in Science and Technology (2011)

Other impacts

Finally, BRTs showed potential impacts in other areas, such as **savings in bus fares, reduction of crimes, employment and health benefits**. It is necessary to underline that these impacts have been mainly observed outside the European context and are not necessarily transferrable to Europe. However, the eBRT2030 project contains a strong international dimension and seeks to replicate its future innovations in other contexts and regions (Latin America and East Africa for examples). For these reasons these impacts are presented below as it is still important to point out the potential impact of BRT deployment in certain areas even if occurred mainly outside Europe.

Saving in average bus fares was observed in Jakarta, Bogota and Lagos, although reducing monetary travel costs is not always a stated objective of BRT (Venter, Jennings, Hidalgo, & Pineda, 2018), while "fare unfairness" is also evidenced in some BRT system (i.e. Johannesburg's BRT pricing scheme focusing on middle-income population and Lima's BRT fares extending the lower affordability of the poor) (Cervero, 2013) (Oviedo, Scholl, Innao, & Pedraza, 2019).

Reduction of crimes in areas of well-lit and secured BRT stations is evidenced. In Bogota a drop of 85% of the crime in the area around Av. Caracas, was attributed to the increased and better organised economic activity and movement around the TransMilenio system. Petty crime, though (i.e., pickpocketing), might be a negative effect of a BRT system operating under crowded stations and buses (Carrigan et al. 2013).

BRTs' impact in **comfort** (travel and/ or waiting) are also seen as positive, when compared to bus or even rail services. A typical example is Adelaide, where customers rated BRT more highly than on-street bus or rail services (Cervero, 2013).

BRTs' developments have an impact on **employment,** directly or indirectly. New jobs are created in construction, operations and maintenance (i.e., In TransMilenio, Bogotá, between 1,900 and 2,900 permanent jobs were created in operations, plus 1400 to 1800 jobs per month in construction (Hidalgo and Huizenga 2013). However, replacement of traditional services, which often accompanies BRT deployment, might bring more important impacts, such as the reduction of paratransit services, which are significant source of employment of low-skilled workers in some cities, or drivers' job losses (Venter, Jennings, Hidalgo, & Pineda, 2018).

Relevant to the **health** benefits of reduced road fatalities and injuries, BRTs can also directly contribute positively to **physical activity**: BRT systems spacing often implies longer walking distances and higher operation speeds are found to increase passengers' willingness to walk to stations. In Mexico City, passengers using the Metrobús walked on average an additional 2.75 minutes per day than previously. Similarly, users of the Beijing BRT added 8.5 minutes of daily walking as a result of the usage of the BRT system (Carrigan et al., 2013). **Reduced exposure to air pollutants**, attributed to cleaner vehicles operating in BRT corridors and reduced exposure time due to reduced travel times, can result in significant benefits for the public health as well. Relevant analysis in Mexico City estimated that the BRT Metrobús Line 3 prevented more than 2 000 days of lost work due to illness, 4 new cases of chronic bronchitis and 2 deaths per year, saving an estimated USD $4.5 million (Carrigan et al., 2013). Spillover effects, though, should be considered, so that environmental benefits from a BRT system introduction are not offset by environmental burdens to peripherally located areas and communities.

5 EBRT TECHNOLOGY STATE OF ART

As presented in section 4.4, the electric BRT system has three main components: vehicle, infrastructure, and operations. This section outlines the technology state of art at the starting point of the eBRT2030 project, capitalising on the readiness of the electric bus technology and looking towards improved maintenance and operations, integrated charging solutions, and connectivity and automation enablers.

Just a decade after the initial trials and pilots of the EU-funded ZeEUs project (Zero Emission Urban Bus System)[45], it is now possible to **showcase the readiness of electric bus technology for demanding routes like BRT systems**. This significant milestone highlights the commitment from all the stakeholders including many EU-funded innovation initiatives fostering such rapid progress and advancement in the field, demonstrating the viability of electric buses to meet the high demands of public transportation while contributing to a sustainable future.

5.1 VEHICLES - ELECTRIC BUS TECHNOLOGY READINESS

Battery electric buses are all-electric or purely electric vehicles with an electric propulsion system that uses chemical energy stored in rechargeable battery packs. Battery electric vehicles (BEVs) use electric motors and motor controllers for propulsion instead of internal combustion engines (ICEs). They have no ICE, fuel cell, or fuel tank and derive all their power from their battery packs.

Trolleybuses are dynamically charged electric buses through direct contact between the trolleybus' poles and the overhead wires. The development of battery technology enabled battery trolleybuses to run on electric mode independent of the overhead wires for part of their route while maintaining full operational capabilities.

5.2 INFRASTRUCTURE – CHARGING STRATEGY AND INTERFACES

The charging infrastructure needed to power the buses depends on the technology and charging strategy implemented. The specific service characteristics and boundary conditions (route length and profile, demand, climate, infrastructure availability and deployment feasibility…) will determine the vehicle design including the battery capacity according to the optimal charging strategy.

[45] ZeEUS was co-funded by the European Commission under the 7th Research & Innovation Framework Programme, Mobility & Transport Directorate General under grant agreement n° 605485.

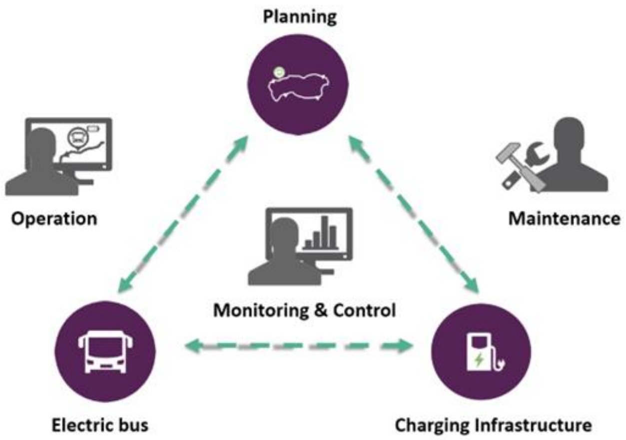

Figure 11. Bus system approach

5.2.1 CHARGING STRATEGY

The charging strategy is the approach to keep enough or optimal state of charge (SoC) of the energy storage systems on board to ensure a satisfactory public transport service delivery of the vehicle according to the design and plan. The current state of deployment of the technology shows two main categories of charging strategies: static and dynamic.

1. Static charging

In this scenario, the vehicle remains stationary while being charged. In all static charging strategies for electric buses, an off-board DC charger is utilised, which is located near the charging point. The connection between the charger and the e-bus can be done manually through a plug-based connection or automatically with pantographs.

a. Overnight (depot) charging

Overnight charging refers to charging the buses between two different duties, usually overnight but not exclusively. Overnight charging is done at the depots in most networks and usually implies the charge of multiple buses simultaneously to ensure the bus fleet is ready for the following duty cycle. Overnight charging is usually associated with slow charging at a low power (30-150 kW for 300-400 kWh battery capacity, 3 to 7 hours) and buses connect to the charging infrastructure through plugs or pantographs. State-of-the-art smart charging management tools allow adjusting the power and charging times at a fleet level to ensure the availability of the vehicles according to the next days' service plan while optimizing energy consumption, grid stabilisation and caring about the state of health of the batteries to maximise lifetime.

b. Opportunity charging

On the other hand, opportunity charging means the use of charging points at given locations of the network (line end-stops, close-by depot or charging hub, etc), to boost charge during daily operation. Although the charging time will need to be included in the bus and drivers' scheduling, the impact on operations against vehicle weight trade-off allows the introduction of energy buffers to avoid service disruption in case of temporary infrastructure unavailability. Interoperable high-power fast charging

Figure 12. Opportunity Charging in Barcelona
Copyright: © Miguel Ángel Cuartero

infrastructure with ranges between 290 kW and 600 kW[46] – allowing to transfer within minutes (certainly below 15 minutes as reference value) of the necessary amount of energy – has proven to be ready for mass deployment when opportunity charging is the optimal or chosen choice for the electrification of BRT routes. For this cases, conductive automatic charging infrastructure through pantographs (panto-up or panto-down) is needed.

c. Flash charging

Flash charging is a particular case of opportunity charging in which the energy storage systems receive quick energy boosts at high power (600kW[47] or beyond) at several stops along the route matching the dwelling time at stops. Typically, each top-up delivers between two to three kilowatts of energy in seconds as the order of time magnitude. Because the bus travels very short distances in between charges, the size of the Energy Storage System (ESS) is considerably smaller than the same vehicle operated under other charging strategies, although the infrastructure planning and investment in public space is in turn much higher.

2. Dynamic charging, in-motion charging

Dynamic charging allows vehicles to be powered and charged while in motion connected through poles to overhead wires. Batteries on trolleybuses are typically charged dynamically using the existing trolleybus catenary through in-motion charging, although top-up can be complemented statically too at terminus stops. In-motion charging (IMC) allows trolleybuses to run off-wire for a section of the line, extending the range of the electric bus operations, which can theoretically achieve unlimited range and uninterrupted operation, even while utilizing a smaller battery.

Figure 13: In-Motion Charging Trolleybus in Prague
Copyright: © DPP

[46] D11.6 – ASSURED Technical Result, Report, EU Horizon 2020 Project Grant No. 769850
[47] D11.6 – ASSURED Technical Result, Report, EU Horizon 2020 Project Grant No. 769850

Dynamic charging can be also performed with underbody connections or wireless, although only small pilots have been conducted so far and big scale deployments are not foreseen in the short to medium term.

5.2.2 CHARGING INTERFACES

There are a variety of interfaces that connects the electric bus to the charger. This section describes the most used applications for bus electrification in Europe.

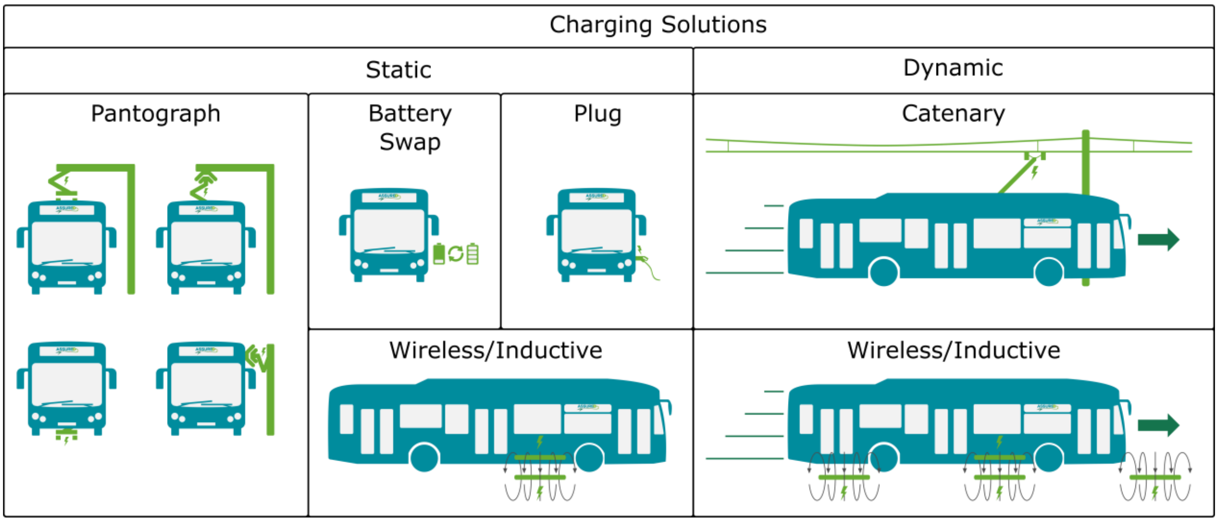

Figure 14. Charging solutions
Source: ASSURED pre-normative technology roadmap

1. Conductive charging

Conductive charging employs physical connection between the charger and the vehicle. Several connectors are in use commercially, including:

a. Plug-based solutions

In plug-based charging, the vehicle is connected to the charging equipment using plugs and cables[48]. Cable-based charging interfaces are typically deployed at the depots, and they consist of the Combined charging system (CCS2) connector in Europe and North America, CHAdeMO in Japan, and GB/T in China. CCS 2 interfaces are designed to deliver high-power DC current up to 350kW and use signalling as a means of communication, defined in the IEC 62196-3 standard, while CHAdeMO can accept up to 400kW and uses CAN communication. GB/T, like CHAdeMO, also uses CAN communication and is

[48] https://assured-project.eu/storage/files/public-pre-normative-technology-roadmap-and-new-use-cases-in-electric-bus-and-truck-charging-final.pdf

widely used in China. Regardless of the connecter type, the cable needs to be manually inserted into the corresponding slot in the e-bus body for charging.

b. Automated charging device solutions

Automated charging solutions utilise a device and standardised communication systems to physically connect the charging infrastructure to the vehicle and ensure a safe and successful power transfer when the vehicle reaches the charging position.

The most used devices are pantographs mounted either on the roof of the buses (panto-up solution) or on infrastructure (panto-down solution); panto-up solutions are the most commonly used in the European context at the moment.

2. Inductive charging

Inductive charging refers to transferring energy from the charger to the vehicle not physically but wirelessly. Wireless charging is typically divided into two primary technologies: capacitive charging and inductive charging. Capacitive power transfer is suitable for low-power applications, while inductive power transfer is employed for high-power applications (AL-SAADI, et al., 2018). Inductive charging operates by utilising an electromagnetic field to transfer energy between two objects via electromagnetic induction. This is commonly achieved through the use of a charging station. Energy is transmitted via inductive coupling to an electrical device, which can then utilise that energy to charge batteries or power the device. Inductive charging relies on high-power inductive energy transfer between components located underground and receiving equipment installed beneath the vehicle.[49] However, according to the ASSURED[50] pre-normative technology roadmap, "Static and dynamic charging solutions have been developed and being tested for HD EVs (SOLUTIONSplus, 2020; Kane, 2021). The market share of inductive technologies may increase slightly after the relevant standards are published.

Figure 15. Inductive charging
Source: © techxplore.com

Nevertheless, these solutions will not be as popular as conductive charging solutions, unless their efficiency for HD EVs in terms of cost and energy transfer is proven and their safety concerns are addressed".

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[49] https://assured-project.eu/storage/files/public-pre-normative-technology-roadmap-and-new-use-cases-in-electric-bus-and-truck-charging-final.pdf

[50] https://assured-project.eu/

5.2.3 CHARGING TRENDS FOR E-BRT

For battery electric buses, the most common charging technologies are conductive, via manual connectors, roof-mounted pantograph, infrastructure-mounted pantograph, ground-based automated connection devices, and flash-charging.

The ASSURED Clean Bus Report (2022) gathers data of 100 cities and bus systems surveyed in Europe, with an aggregated fleet that represents one quarter of the European bus stock. The report shows that for fleets hosting more than 10 battery-electric vehicles, **the most common technology is the conductive manual plug for overnight charging, followed by the automated roof-mounted pantograph**. Regarding the automatic connection device, roof-mounted pantographs are the most common among the surveyed urban bus systems being present in 20 cities, followed by infrastructure-mounted. It is worth mentioning that these results were consistent with the ASSURED pre-normative technology roadmap which presented the foreseen developments in different aspects of charging technologies of heavy-duty electric vehicles by creating a clear overview of the popularity of charging technologies and the end users' needs. According to this roadmap, **pantograph on the roof and plug-based charging are currently the most used charging technologies and the trend is very likely to continue in the future**. Static and conductive charging have higher potential, as compared to dynamic and wireless charging.

Furthermore, the EU-funded ASSURED project contributed to advancing this vision. Battery-electric BRTs and trunk lines would preferably rely on opportunity charging, while feeder lines are expected to rely on overnight depot charging beyond 2024. In this light, the interoperable, high-power fast charging solutions developed and tested in ASSURED have the potential to improve European BRT systems and operations by enabling e-BRT lines with superfast high-power charging capabilities. Naturally, the roadmap also includes the trolleybus and battery-trolleybus technology as an alternative for hilly landscape areas and heavy demand and large service span operations, especially suitable when infrastructure is already in place.

5.3 OPERATIONS – SMART CHARGING AND CONNECTED OPERATIONS

5.3.1 SMART CHARGING SYSTEM FOR ELECTRIC BUS FLEETS

Electric BRT bus fleets imply a significant number of vehicles to fulfil heavy-duty cycles in busy routes, hence high energy demand is to be provided. In this sense**, defining a suitable energy management strategy is a key element to ensure viable and sustainable electric bus deployment and operations**. With so-called **smart charging (V1G) it is possible to control the time and magnitude of charging power from the electricity grid to the vehicles**.

On the opposite, uncoordinated charging is where e-buses connect to the charger to be charged with the maximum allowed power by the connector/charger until fully charged (100% state of charge) without considering the number of e-buses that are connected simultaneously to the chargers and their impact on the grid infrastructure. In the case of a high number of e-buses connected to be charged simultaneously, there would be a high impact on the grid in terms of the voltages on the bus bars, distribution system operator transformer load profile, and line rating. In addition, uncoordinated charging has an impact on the operational cost of the e-buses since the energy price in peak loads is higher than the price in off-peak hours according to the distribution system operators' (DSO) grid load profile. Furthermore, as a high peak is achieved (for a single moment in one year), the distribution capacity price increases accordingly (for one complete year).

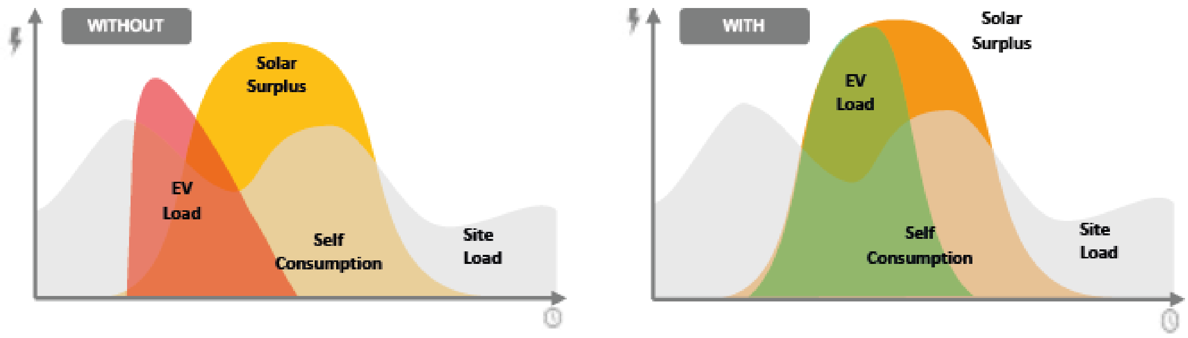

Figure 16. Smart charging system potential gains.
Source Enel-X

For **electric bus fleet operators, it is very important to have a suitable smart charging management system (CMS) to ensure that all buses have the required state-of-charge to carry out their duty as per their schedule**. This requires a centralised application that monitors and consolidates in real-time the information sent from the buses and the chargers belonging to the bus operator.

These solutions not only allow planning the charging phase of the buses and optimising energy consumption, but also to focus on the daily management of the depot in the face of uncertainties such as the late arrival of a bus or the breakdown of a charging station. Real-time notifications of technical failures allow the dedicated staff to intervene quickly and solve any issue in the charging process.

In relation to the control of the charging process and automatic dispatch of vehicles (e-VSP), when charging begins, each charging process is assigned a priority that depends on the intended use of the vehicle. Based on this priority, charging processes throughout the garage are balanced without overloading the transformers or the grid connection. During the charging, charge levels are continuously recorded and compared to the power requirements of the planned trip. Once the vehicles are sufficiently charged, trickle charging is activated. If for some reason the power demand cannot be met, a new priority is assigned, or other vehicles are suggested automatically. The 'fitting out' starts right on time based on the start time of the cycle. All warehouse processes such as maintenance, cleaning and repair are taken into account when charging.

These solutions make it possible to optimise the vehicle assignments over multiple days. (i) Planning of day and night loading activities; (ii) Programming and optimisation of activities recharge for several days; (iii) Planning of recurring maintenance activities; (iv) Use of what-if scenarios to assess the impacts of different SoCs on the vehicle schedule; (v) Optimisation of energy needs in advance.

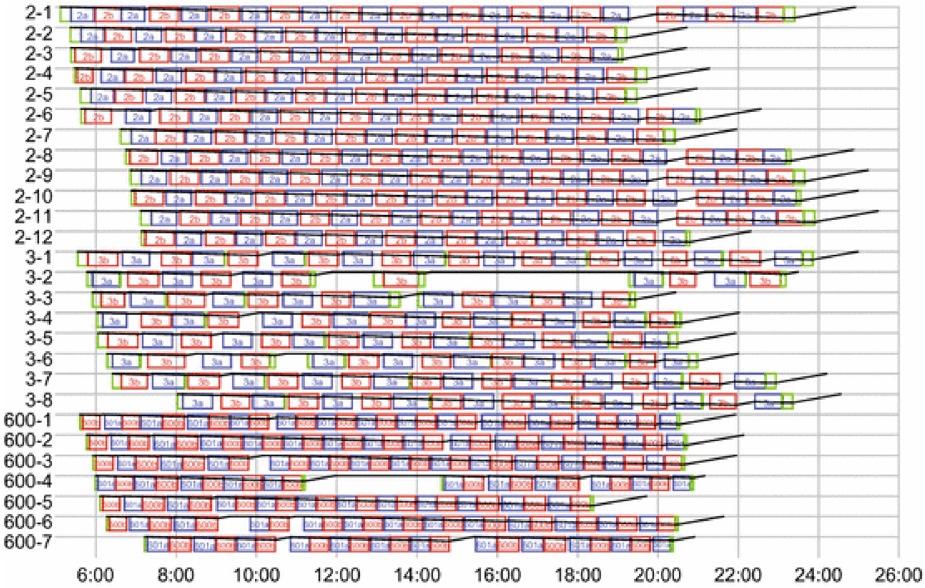

Figure 17: Vehicle schedule for the urban service of Leuven, using Model 2c

Notes:(Column Generation with Lagrangian Relaxation) for optimisation and a battery capacity of 244 kWh. Source: (van Kooten Niekerk, van den Akker, & Hoogeveen, 2017)

In the last years, many innovative solutions combining depot management and electric fleet management are appearing in the market. Some solutions follow the Open Charge Point Protocol (OCPP) standard and the VDV 463 standard on interconnection of charging management systems, depot management and ICTS systems.[51]

Some of these applications are the JuiceNet Manager eBUS and ELECTRA from the eBRT2030 partners Enel X and ETRA. As an example, JuiceNet Manager is a cloud-based platform for electric vehicle load management and optimisation. It uses patented communication, control, and intelligence to aggregate and manage charging station demand based on historical patterns, real-time inputs, and information about the grid. It can improve grid reliability, grid economics, improve local air quality, and reduce the total cost of ownership (TCO) of maintaining bus fleet by reducing charging costs.

5.3.2 CONNECTED FOR PERFORMANT OPERATIONS

This section outlines the various types of technologies that are primarily used to enhance the performance of bus operations. These technologies can significantly contribute to a cleaner, safer, and more efficient transport system and there are many that can be utilised when designing and implementing BRT systems.

Automatic Vehicle Location (AVL)

Automatic Vehicle Location (AVL) technology is used to track and monitor the real-time geographic location of the buses by means of GPS devices or other location-tracking methods. Usually, the data is then transmitted to a centralised control centre. This vehicle location data, from one or more vehicles, may then be collected by a vehicle tracking system to manage an overview of vehicle travel.

[51] VDV = Verband Deutscher Verkehrsunternehmen

In most modern electric BRTs, the location is determined using global positioning systems (GPS) and the transmission mechanisms are short messaging systems (SMS), general packet radio services (GPRS), or a satellite or terrestrial radio from the vehicle to a radio receiver. A single antenna unit covering all the needed frequency bands can be employed. The Global System for Mobile Communications (GSM) and evolution-data optimised (EVDO) are the most common services applied, because of the low data rate needed for AVL, and the low cost and near-ubiquitous nature of these public networks. Other options for determining actual location, for example in environments where GPS illumination is poor, are dead reckoning, i.e., inertial navigation, or active radio frequency identification (RFID) systems or cooperative real-time locating systems (RTLS). These systems may be applied in combination in some cases. In addition, terrestrial radio positioning systems using a low-frequency switched packet radio network have also been used as an alternative to GPS based systems.

GPS and GPRS technologies allow real-time tracking and monitoring of the vehicles' positions, speeds, routes, and other operational parameters. This information is crucial for assessing the performance and efficiency of the fleet, identifying potential issues, and optimizing the routes and schedules.

Some likely impacts of the application of an AVL system extracted from (National Academies of Sciences, Engineering, and Medicine, 2007) are:

- Improved system control. The system in general can be calibrated with greater ease to distribute service times and coverage adequately through the application of Traffic Signal Priority (TSP).
- Improved bus safety. In an emergency, the control centre can relay vehicle location immediately to authorities.
- Improved quality of service. Passengers can be notified in real time of the location of the next bus and its expected arrival time.
- Improved system integration. Vehicle connections can be better scheduled and controlled by knowing the location of each vehicle.
- Reduced need for voice communication. This can simplify vehicle operation for the driver.

Transit Signal Priority (TSP)

Priority is one of the key features of BRT systems. TSP can be activated by BRT vehicles that operate in their own designated lane or alongside other vehicles on a street (known as 'mainline' priority), or by using an auxiliary lane at an intersection (known as a 'queue jump'). In mainline TSP, the green signal may be extended, or the red signal may be shortened to give priority to BRT vehicles and decrease intersection delay. In a queue jump, the transit vehicle receives a separate green light to pass through the intersection before other vehicles. In both cases, the signal timing is adjusted to maintain the signal cycle length and coordination of the signal system.

TSP is distinct from signal pre-emption, which interrupts regular signal operations and changes the signal cycle length to accommodate special events such as emergency vehicles or trains at railroad crossings.

In many cases, the automated TSP will be tied to an AVL system that can provide priority only if the corresponding bus is behind schedule or with the Automatic Passenger Counting (APC) that can provide priority depending on the number of people on-board. The priority is based on the TSP logic programmed into the traffic signal controller. TSP strategies include passive, active, and real-time priority.

Automatic Passenger Counting (APC)

Automatic passenger counters (APC) keep track of the number of passengers boarding and alighting at each stop and the total number of passengers on the vehicle. They use sensors at doorways to detect passenger movements.

APC systems create electronic records at each bus stop, including the stop's location, date and time, door opening and closing times, and the number of passengers boarding and alighting. One of the primary advantages of using an APC system is that it offers a continuous record of the number of passengers traveling on a transit route and allows for quick data analysis (e.g., enhancing the Origin Destination matrix).

The APC units are linked with a monitoring system, which includes integration with the AVL and TSP systems. If it is integrated with the TSP system, the buses are given conditional priority based on a minimum number of passengers on board. However, in certain cases, the APC has been installed as a standalone system with its own GPS, separate from the AVL system. This can occur either because the APC was implemented before the AVL or because the APC was installed after the AVL but with a different vendor. Such situations result in incomplete and unmatched data and increased maintenance costs. Furthermore, additional processing is required after data collection to match the APC data with the AVL data.

In general, transport operators that installed APC systems have been able to reproduce the current ridership with approximately 95% accuracy, as determined by field checks.

Other Technologies

According to the European Commission, Intelligent Transport Systems (ITS) can significantly contribute to a cleaner, safer, and more efficient transport system.

Some of these technologies aim at automating the operations as much as possible and optimise the performances. A few examples of these technologies are collision avoidance systems, lane guidance (mechanical guide wheel, optical guidance, magnetic guidance, GPS guidance), precision docking (Kassel kerb, low friction rub bar, mechanical guide wheel, optical guidance, magnetic guidance), etc. Some of the technological innovations of the eBRT2030 project will demonstrate the use of these technologies for enhanced operations, including for example autonomous bus stop docking and autonomous driving navigation system and autonomous positioning at charging station (OppCharge, Pantograph up).

All these technologies can be integrated into BRT systems to potentially increase their efficiency, safety, and performance. The figure below presents some examples of the technologies discussed above.

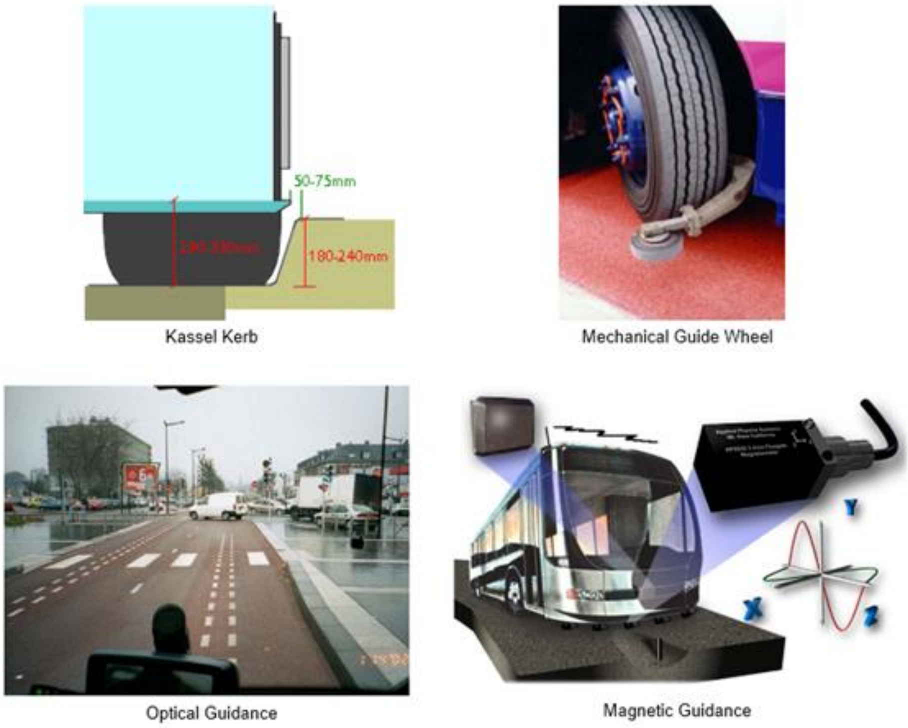

Figure 18. Examples of precision docking systems
Source: (American Public Transportation Association, Implementing BRT Intelligent Transportation Systems, 2010)

Other technological applications can be used to improve the passengers' experience. Amongst others, the following technologies can improve the users' experience:

- Traveller information: Information about the vehicle, incidents, estimation of arrival (Information about the vehicle), etc.
- Automated Fare Collection (AFC): ticketing system in public transport where the fare is no longer paid directly but via ticket vending machines, online services or other methods. New systems include **contactless payments** via a bank card or other medium, such as smartphone or smart watch.
- Electronic payment: the option to purchase a single ticket for a multimodal trip (use of magnetic stripe and smart card technologies).

ITS technologies, like the aforementioned, have been proven to help public transport operators and relevant authorities increase safety and efficiency[52]. Remote monitoring, management and assistance of vehicles, and collection of passenger activity helps provide additional safety and security to users. All of these technologies have demonstrated that they are capable of reducing travel time both by improving the operation of the vehicle and the overall operation of the network[53].

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[52] T. Vaa ; M. Penttinen; I. Spyropoulou. Intelligent transport systems and effects on road traffic accidents: state of the art. IET Digital Library Volume 1, Issue 2, June 2007, p. 81 – 88.
[53] Stawiarska, E.; Sobczak, P. The Impact of Intelligent Transportation System Implementations on the Sustainable Growth of Passenger Transport in EU Regions. Sustainability 2018, 10, 1318

Most of the ITS technologies highlighted will be part of the implementation of the new generation of eBRT systems; and will potentially have a positive impact to support the goal of the project of reducing emissions, and congestion, supporting the transition towards zero emission sustainable and safe transport.

Figure 19. Connexxion AML R-net with passengers' information at stop
© Connexxion

5.3.3 TIMETABLING AND SCHEDULING

A good timetable can mean different things depending on passengers' needs and the desired operations. If some operations seek to achieve the regularity of the service, others strive for a specific frequency, while in some other cases the objective is the smallest difference between actual and desired frequency. Although timetabling is difficult because of these varying objectives, its main objectives are minimising waiting times and synchronizing departures while keeping a high level of safety, quality of service and comfort.

On the other hand, vehicle and drivers scheduling involves assigning buses and drivers to a service duty, which is aimed to cover the trips while meeting operational constraints.

The planning department in the operators usually take care of this task, assisted by software solutions to optimise the service. Electric buses have introduced new variables in the planning process, including charging time, locations, and battery state of charge and health. Ignoring these factors result in suboptimal plans yielding to additional vehicles and/or drivers needed.

6 BRT CONCEPT FOR EBRT2030

6.1 METHODOLOGY, INPUTS AND VALIDATION

This document identifies and describes the current state of deployment and state of art of BRT technology as a base for the eBRT2030 project developments. At the same time, the reports put additional efforts in order to establish a preliminary benchmark for European and electric BRTs. The work used a mixed methodology that combined desk research (literature review) with interactive sessions with experts such as workshops and interviews.

The methodology encompassed the following steps:

1. Initial workshop

An initial workshop took place in the frame of the eBRT2030 kick-off meeting (Brussels, 3rd of February 2023) to identify BRT features from selected systems worldwide and consolidate a list of parameters. Experts and stakeholders from various European BRT systems participated, and they classified the parameters as either physical features or performance requirements. This step provided a comprehensive understanding of BRT system characteristics and their relevance to the European context.

2. Literature review

The extensive literature review encompassed BRT and bus system literature from multiple sources. The review incorporated research papers, reports, guidelines, and case studies, providing a comprehensive knowledge base as a state of art and building towards establishing the benchmark of European BRTs. Additionally, the work explored parallels and synergies between BRT and urban rail modes (tramways, light rail, and metro) as inspiration to understand the characteristics and role of BRTs as a transport mode and characterise the lines and corridors by their physical and operational performance.

3. Interviews with European demos

The paper benefited from additional detailed information from the demos use case collected through interviews with representatives from the six European BRT demonstration projects, along with the Nantes busway in France. These interviews gathered detailed design information, constraints, and experiences of implementing BRT systems in Europe in a wide variety of local contexts and approaches. The insights gained helped address specific challenges and considerations associated with European BRT systems.

4. Workshops with UITP Committees

The report involved UITP working bodies through dedicated workshop organised with the UITP Bus Committee (Coventry, 26th of April 2023) and UITP Trolleybus Committee (Cagliari, 4th of May 2023). Members from these committees discussed the goals and requirements for European BRT systems from their extensive expertise in planning and operating bus systems and outstanding commitment to advancing bus mode and public transport network performance. The workshops challenged the initial benchmark proposals and facilitated discussions among the project partners to develop a useful and comprehensive scorecard for public transport stakeholders. All in all, the involvement of UITP Committees ensured alignment with industry expectations and needs.

5. Final validation workshop with international stakeholders:

A final validation workshop took place during the UITP Global Public Transport Summit (Barcelona, 5th of June 2023), where international stakeholders from the five continents participated. This workshop served as a platform to fine-tune the parameters and thresholds previously established. The event enhanced the visibility around the BRT topics in the public transport agenda worldwide as well as shed the lights around the eBRT2030 project and its related positive effects for citizens benefiting from enhanced bus services now and in the future. The input and experience of international experts provided valuable perspectives, ensuring the benchmark's relevance and applicability focusing on Europe but backed from a global scale.

This collaborative and inclusive approach followed in this task towards delivering this document and setting the scene for the future developments in the project, ensures that the project benefits from the collective wisdom and best practices of industry experts.

6.2 BENCHMARK AND BRT SCORECARDS

The purpose of the proposed scorecard is to support the characterisation of existing BRT systems in Europe and experienced cities in other regions. The scorecard functions as a tool for understanding the benchmark of European BRTs and for setting the scene for further innovation.

This purpose and function differ from previously developed BRT assessment tools, of which *The BRT Standard* (ITDP, 2016) is the most renowned. "The BRT Standard scoring system was created as a way of protecting the BRT brand and offering recognition to high-quality BRT corridors around the world" (ITDP, 2016, p. 10). As already outlined in previous chapters, the difference is in the purposes and the need for a more context-specific tool adapted for European BRT systems or corridors. For this reason, *The BRT Standard* is not directly applicable in eBRT2030.

In addition to *The BRT Standard*, an *Assessment Tool for Swedish BRT* (Odbacke, 2018) was developed some years ago (and is currently being revised following the first years of use in BRT planning). The Swedish scorecard has the objective to support discussions amongst different stakeholders and to find a common level of ambition in the early stages of BRT projects. Again, this purpose differs from the idea of the scorecard of eBRT2030 outlined hereafter.

Thus, *The BRT Standard* and *the Assessment Tool for Swedish BRT* in their current forms do not suit the purpose of this task but are nevertheless valuable sources of inspiration. The parameters and scores used in this scorecard are to a large extent based on these two existing models. Over the course of the project, through knowledge development and discussions, this characterisation exercise will be further developed and fine-tuned.

It is important to note that the scorecard's aim is not to rank performance or state of deployment of different BRT systems based on a single output but to provide a visual result to show the strengths and areas of improvement of the eBRT system to encourage developments in a certain cluster of the BRTisation parameters building up the BRT concept as defined in section 4.4. Therefore, the scorecard aims to be an inspiration for enhanced levels of ambition rather than provide a ranking of any form.

6.2.1 BRT BENCHMARK AND CHARACTERISATION PROCESS

For the purpose of setting a benchmark for BRTs, i.e., the set of parameters and minimum requirements to be fulfilled to qualify as BRTs, three entry parameters have been identified. There parameters are here considered the fundamental BRT-defining elements and they help to understand and clarify the BRT concept for the European urban context in the frame of eBRT2030.

As mentioned previously, **right-of-way achieved mostly through dedicated physical infrastructure and complemented by virtual public transport priority measures** is a defining characteristic of BRTs with a strong and direct impact on the commercial speed and reliability/punctuality of the bus service. Nevertheless, the scale, level of segregation and infrastructure-design parameters are amongst the ones with a higher sensibility to the urban and regional context (reference architecture).

Secondly, **service frequency and service headway** have been identified as a shared parameter across BRT systems globally contributing to the high level of service inherent to BRTs.

Thirdly, **it is crucial for the BRT line or corridor to be "declared" or acknowledged** by the key stakeholder (PTA or PTO) and recognised as such at all levels in the specific urban context, as it generates a thrust that plays a key role in the BRT implementation and improvement of the network. This aspect percolates in many different ways in the BRT system from passenger information or branding to operational excellence. In essence, treating the BRT service with the same level of (low) flexibility as equivalent rail-based modes (typically light-rail) encapsulates the ways in which this acknowledgement supports always keeping and enhancing the quality and performance of the BRT system.

In this first attempt, the thresholds considered for the BRT benchmark are as follow:

- Right-of-way (bus lanes or bus-only corridor) on at least 20% of the corridor
- Weekdays daytime frequency of 4 buses per hour or more
- Route or corridor is acknowledged as core and/or flagship in the network with special treatment.

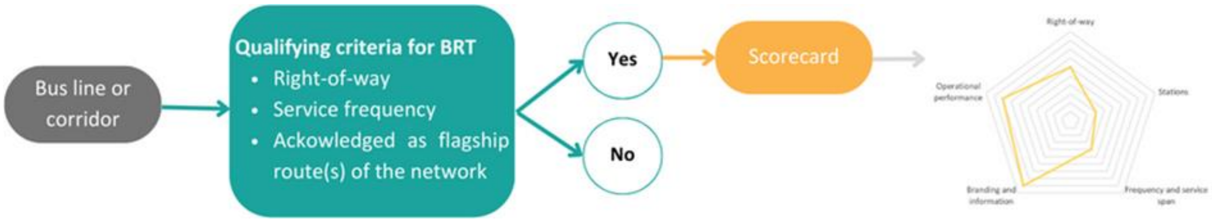


Figure 20. Characterisation process

Beyond the benchmark, the tool is conceived to evaluate certain entry parameters against preliminary thresholds yielding identifying a BRTisation stage for the different characteristic clusters that are explained below.

At this point of the project, the tool does not provide an overall level of BRT according to certain input data but a visual result in the form of a spider map that suggests the potential areas of improvements of the system to enhance performances or future developments.

6.2.2 SCORECARD STRUCTURE

The scorecard is structured around five categories:

- Right-of-way
- Frequency and service span
- Stations
- Communications
- Operational performance

The categories roughly correspond to the categories definited in *The BRT Standard* (ITDP, 2016), with a certain degree of simplification and adaptation to better fit the purpose of the scorecard described above. In order to highlight the main differences, the parameters in the category “BRT Basics” in *The BRT Standard* have been transferred to other categories in the eBRT2030 scorecard as the BRT baseline definition in *The BRT Standard* is not applied in eBRT2030. Additionally, the category “Access and Integration” in *the BRT Standard* has no counterpart in eBRT2030 because the corresponding parameters are not applied this time.

However, in light of embracing the innovations to be developed in this project and building towards the BRT concept for all, two new categories or addons have been preliminarily assessed and will be reviewed and considered during the project. The categories proposed at this point are:

- Zero-emission fleet and smart energy
- Connected and automated

Regarding the practicalities of the eBRT2030 scorecard, each of the five cluster of parameters provides a maximum total score of 100 points and has not been weighted in relation to each other. Furthermore, the total score, encompassing all categories, is not calculated within this setup as it falls outside the intended purpose of the scorecard.

The table below summarises the approach to show the results, in which a certain threshold per cluster of parameters allows the classification of a given BRT system per category or cluster. At this point, the thresholds for BRT level 1, 2 and 3 have been set at 40, 60, and 80 points, respectively. BRT level 0 is anything below 40 points (but meeting the minimum requirements according to the benchmark described above). Additionally, at this point this cross-table allows identifying the impact of the preliminary innovation-oriented categories on the rest.

Table 3. Characterisation parameters assessment

	Level 0	Level 1	Level 2	Level 3	ZE fleet & smart energy	Connected and automated
Right-of-way		40 p	60 p	80 p		
Stations		40 p	60 p	80 p		
Frequency and service span		40 p	60 p	80 p		
Branding and information		40 p	60 p	80 p		
Operational performance		40 p	60 p	80 p		

The abovementioned table was used in the different workshops with the participation of experts to set and validate the categories and preliminary thresholds.

6.2.3 OVERVIEW OF PARAMETERS

Each of the five categories presented before corresponds to a cluster of parameters listed below.

Right of way
Busway separation
Busway alignment
Other vehicles allowed in bus lanes
Bus priority at intersections

Stations
Stop spacing
Bus stop types
Boarding and alighting
Level boarding, vertical gap

Frequency & span
Daytime frequency
Evening and weekend frequency
Weekday operating hours
Weekend operating hours

Communications
Branding
ITS passenger information

Operational performance
Commercial speed
Travel time variability

Figure 21. eBRT2030 scorecard parameters

The scorecard is complemented by a set of background information and parameters that are not object of scoring but that are of added value for the comprehension and understanding of the BRT system.

- Type of BRT: BRT line or BRT corridor
- Urban setting (Urban, Peri-urban, Regional)
- Corridor length (km)
- Ridership (number of passengers per year)

6.2.4 PROPOSED SCORING

RIGHT OF WAY

The 'right-of-way' category aims at capturing the quantity and quality of bus priority infrastructure. The key parameters are weighted by the percentage of segregated bus infrastructure along the corridor, which means that the degree of separation is a central element even though it is not scored in a specific parameter.

In general, there is no need for bus lanes where buses can be operated at free-flow speed at all times – at least not for the purpose of improving the speed and reliability of bus services – but continuous busways may still be justified e.g., for BRT 3 due to the possible effects on the image of the BRT. Keeping in mind that BRT 3 should be of a quality corresponding to a modern light rail service, it should also include restrictions regarding rerouting due to public events etc. However, the scorecard does not entail such details because it focuses on characterisation on a more overarching level.

The percentage of the corridor should be based on the sum of both directions. This means that a section with a bus lane in one direction and mixed-traffic operations in the other direction should be regarded as having 50% bus lanes. This is regardless of whether the bus lane is reversible (e.g., altered driving direction morning and afternoon depending on the direction of peak traffic). However, bidirectional single-lane bus corridors ("single-track" operations) can be regarded as having 100% separated bus infrastructure.

Table 4. Proposed Scoring for Right of Way

Busway separation	Points	Weighted by
Physically separated bus lanes (e.g., by curb or median strip between the bus lanes and other parallel lanes) or bus-only corridor	25	% of corridor
Colour-differentiated bus lane with no physical separation (e.g., "red carpet")	20	
Bus lanes separated by a painted line only	15	
Mixed-traffic operations (no bus lane)	0	

Busway alignment	Points	Weighted by
Median-aligned bus lanes or bus-only corridor	25	% of corridor
Curb-aligned or offset bus lanes	0	

Other vehicles allowed in bus lanes	Points	Weighted by
Bus lanes exclusive for buses (and emergency vehicles)	25	% of corridor
Non-emergency vehicles allowed in bus lanes, e.g., taxis, bicycles, or high-occupancy vehicles	0	

Bus priority at intersections	Points	Weighted by
Grade separated, absolute priority (“railway-like crossings”), or signal priority in combination with turn restrictions (turns across bus lanes forbidden)	25	% of intersections
Signal priority (activated by an approaching bus)	15	
No bus priority	0	

FREQUENCY & SPAN

The ‘frequency & span’ category mirrors the temporal availability of bus services along the BRT corridor.

Table 5. Proposed Scoring for Frequency & Span

Daytime frequency	Points	Weighted by
At least 8 buses per hour during peak and inter-peak periods (roughly from 6 a.m. to 6 p.m. on weekdays)	25	% of corridor (if the service frequency varies between different sections of the corridor)
At least 6 buses per hour	15	
Less than 6 buses per hour	0	

Evening and weekend frequency	Points	Weighted by
At least 4 buses per hour until 10 p.m. all days	25	% of corridor (if the service frequency varies between different sections of the corridor)
At least 4 buses per hour until 10 p.m. on weekdays (but not on one or both of the weekend days)	15	
Less than 4 buses per hour on weekday evenings	0	

Weekday operating hours	Points	Weighted by
Service span at least 19 hours (e.g., from 5 a.m. to midnight), Monday to Friday	25	% of corridor (if the operating hours vary between different sections of the corridor)
Service span at least 17 hours (e.g., from 6 a.m. to 11 p.m.), Monday to Friday	15	
Less than 17 hours service span on weekdays	0	

Weekend operating hours	Points	Weighted by
Service span at least 17 hours (e.g., from 7 a.m. to midnight) on both Saturdays and Sundays	25	% of corridor (if the operating hours vary between different sections of the corridor)
Service span at least 15 hours (e.g., from 8 a.m. to 11 p.m.) on both Saturdays and Sundays	15	
Less than 15 hours service span on Saturdays or Sundays	0	

STATIONS

The 'stations' category focuses on improving travel times and reliability, but also entails factors of importance for accessibility and convenience for the passengers at the stations.

The link between BRT and urban planning has not been included in the scorecard, even though this is an essential element of BRT. The importance of this link cannot be overemphasised.

Here, the terms *bus stop* and *station* are used interchangeably, indicating that a bus stop on a BRT corridor should be designed with the high level of comfort that is typically associated with stations.

As in the right-of-way category, the percentage of stations or bus stops is calculated based on the sum of both directions.

Table 6. Proposed Scoring for Stations

Stop spacing	Points	Weighted by
At least 500 m average inter-stop distance	25	-
400–500 m average inter-stop distance	20	
300–400 m average inter-stop distance	15	
Less than 300 m average inter-stop distance	0	
Bus stop types	**Points**	**Weighted by**
In-lane bus stop with curb extension (platform extension, bus bulb), allowing buses to approach the platform without lateral movement	25	% of bus stops
In-lane bus stop without curb extension	15	
Bus bay	0	

Boarding and alighting	Points	Weighted by
Boarding at all doors is allowed	25	-
Boarding at more than one door is allowed (but not at all doors)	15	
Boarding at all doors is not allowed	0	

Level boarding, vertical gap	Points	Weighted by
Bus stops designed to minimise the vertical gap between the platform and the bus entry without bus kneeling (typically less than 4 cm of vertical gap)	25	% of bus stops
Requirement regarding the vertical gap demands bus kneeling	15	
Requirement regarding the vertical gap is not met	0	

COMMUNICATIONS

The 'communications' category entails parameters concerning passenger information in the BRT corridor.

The network effect is important, and it is essential that the BRT service is an integrated part of the public transport network in the region/area where it operates.

Table 7. Proposed Scoring for Communications

Branding	Points	Weighted by
The BRT corridor is branded (differentiated from conventional bus services in the area), and this branding can be identified on passenger information such as the route map, on all buses, and on all stations	50	-
The BRT corridor is branded, but the branding is not fully implemented (e.g., it does not fully cover all of the three elements described above, only some buses in the corridor are branded, or the branding cannot be identified on all stations)	25	
No corridor brand	0	
ITS passenger information (sum, maximum 50 points)	**Points**	**Weighted by**
At stops, real-time audio-visual "next-bus" information	15	% of bus stops
In buses, audio-visual information about next stop, connecting services, destination, etc.	15	% of buses
Routing and real-time information available on website or smartphone app	10	-
Open data available for third-party information providers (Google maps General Transit Feed Specifications (GTFS) or similar)	10	-

OPERATIONAL PERFORMANCE

The 'operational performance' of the BRT services is assessed through parameters concerning speed and reliability. These parameters are, in a sense, aspects of the operational outcome of the design of the BRT corridor, which is assessed in the other categories.

Table 8. Proposed Scoring for Communications

Commercial speed (during peak hours)	Points	Weighted by
25 km/h and above	50	-
x km/h [15 < x < 25]	5 (x – 15)	
15 km/h and below	0	
Travel time variability	**Points**	**Weighted by**
Equal peak and off-peak travel time	50	-
Peak travel time is x % longer than off-peak travel time [0 < x < 25]	2 (25 – x)	
Peak travel time is 25% longer or more compared to off-peak travel time	0	

Once more, the scorecard described above does not have the aim to rank performance or state of deployment of different BRT systems based on a single output. The scorecard has the objective to visualise the strengths and areas of development of the eBRT system to inspire progresses in a certain cluster of the BRTisation parameters in the defined BRT concept. The scorecard aims to be an inspiration for enhanced levels of ambition of eBRT systems and will be reviewed and re-assessed over the course of the project.

6.3 BRT DYNAMIC MAPPING

The dynamic mapping component within the eBRT2030 project aims at providing a comprehensive and interactive tool that illustrates the current state of BRT systems at a global scale. The dynamic map is a visual and user-friendly representation of the results and determinations described in the previous section.

The dynamic map serves as a valuable resource for practitioners, interested parties, and individuals seeking up-to-date information on BRT systems in the eBRT2030 community, including their technological and infrastructural characteristics. However, its purpose extends beyond being a mere data hub. The map is designed to act as a platform for inspiration, mutual learning, and cooperation. Drawing from the methodology of the eBRT2030 Scorecard previously illustrated, the map showcases strengths, main characteristics, and areas of improvement of the represented BRT systems. This allows users to consult other systems and utilise best practices for specific BRT characteristics as a source of inspiration. The map not only focuses on quantitative data but also includes qualitative data and shared experiences related to the implementation of BRT systems.

To portray all the aforementioned information the dynamic map comprises various elements and pages. The following section outlines the key components of the map and describes their functionalities and content.

A. Overview

The overview page serves as the starting point for users, offering a high-level perspective of the BRT system at display. It provides an initial impression and understanding of the system's main characteristics and boundary conditions such as completeness, size, geographical context, and spatial layout. For instance, users can assess the number of BRT lines, the total length of the system, and gain insights into the system's impact on users and the modal split.

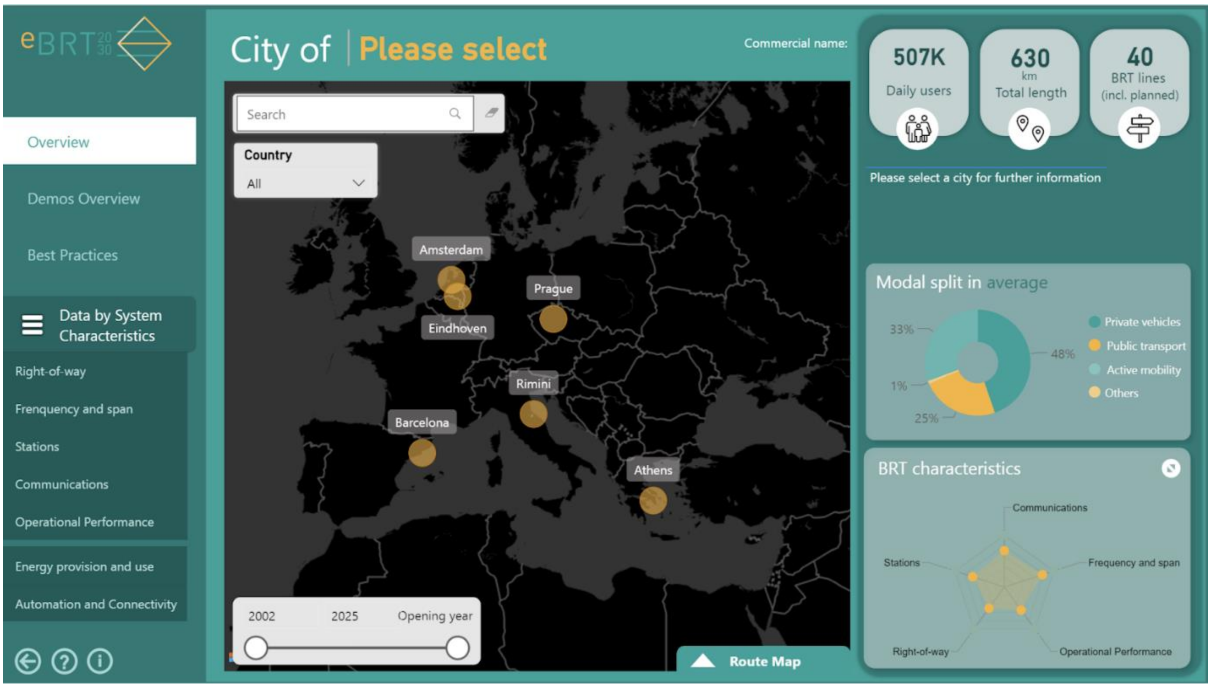


Figure 22. BRT Dynamic Map Landing Page

B. BRT Characteristics

To facilitate in-depth analysis, the map features dedicated pages for each characteristic considered in the scorecard: Right of way, Frequency and span, Stations, Communications, Operational performance. These views present detailed information on infrastructure and right-of-way, bus priority measures, and other operational attributes of the systems depicting the fluidity, availability and accessibility of the considered systems. Furthermore, the data currently available related to the tentative new categories on energy use for zero-emission fleet operations and connectivity and towards automation aspects have been included. This is intended as a living tool for the project, and it will integrate in the future new relevant aspects relevant such as public participation or governance. All the currently considered parameters can be identified in the pictures below.

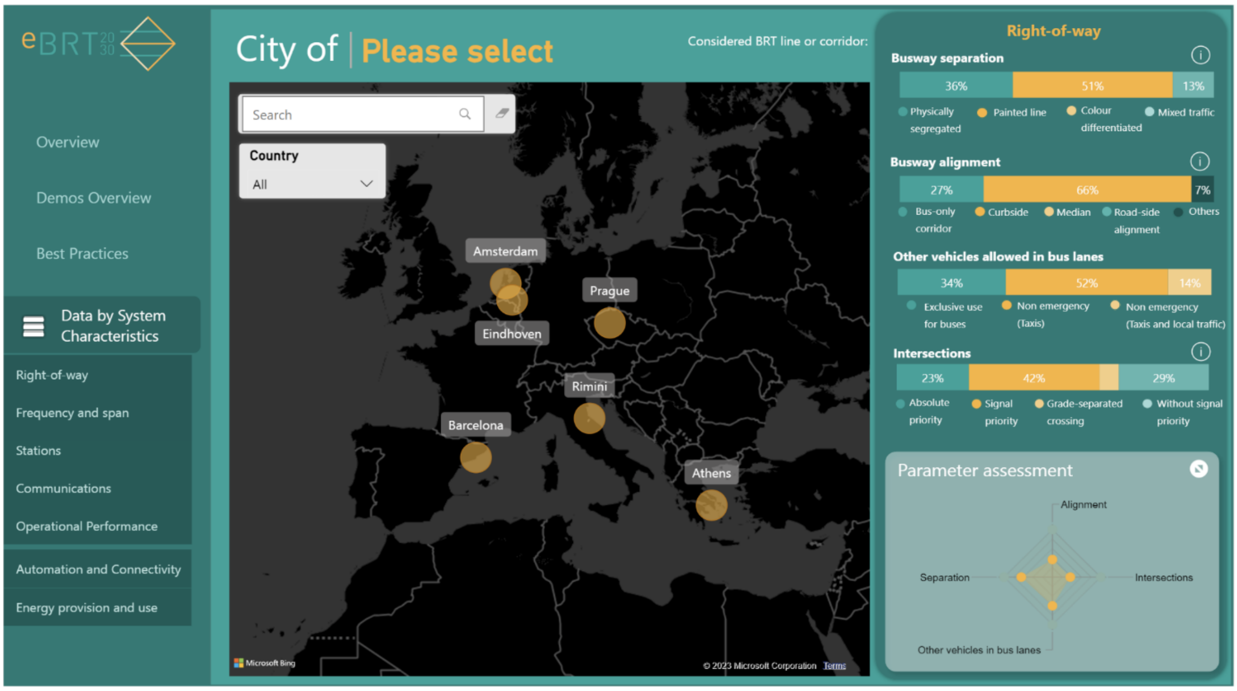


Figure 23. eBRT2030 Dynamic Mapping

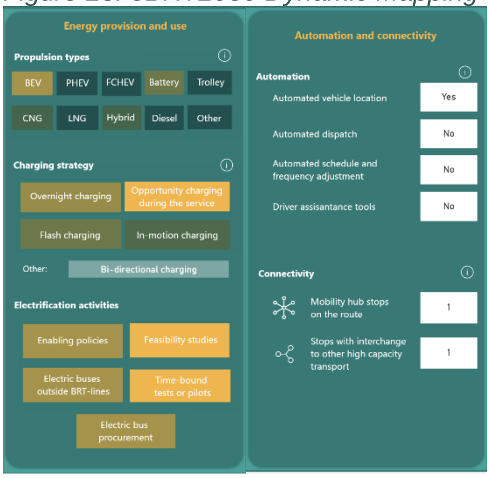
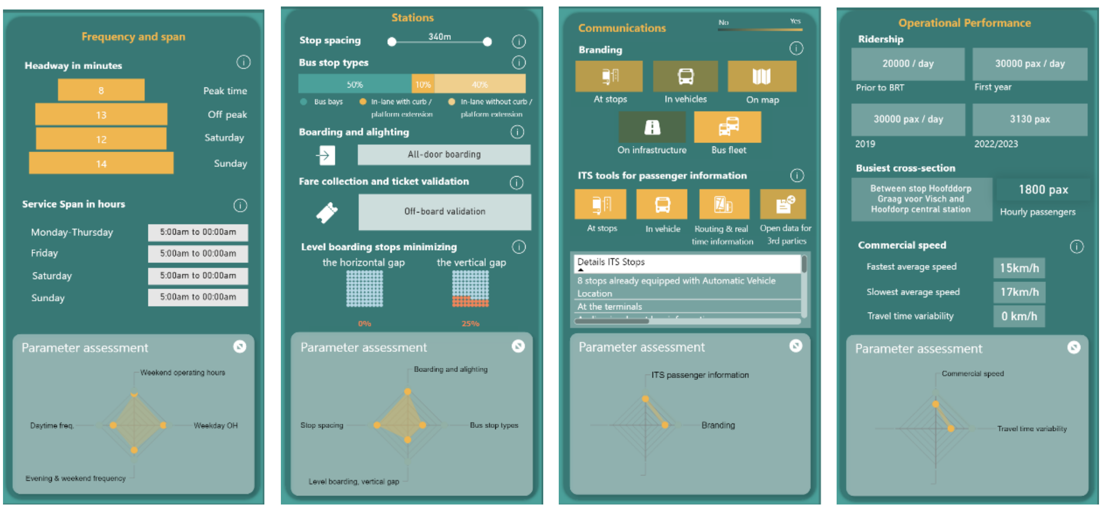


Figure 24. Dynamic Mappings Parameters



C. eBRT Framework Examination

The dynamic map includes a dedicated section where BRT systems are examined based on the scorecard developed within the eBRT project through spider maps, not aiming at comparison between different BRT systems but helping to identify good practices, strengths and areas of improvement. Users can gain insights on the system's main strengths and potential areas for improvement. Spider graphs are utilised to provide a graphic overview. This type of analysis is available for both overarching characteristics and specific attributes within each characteristic.

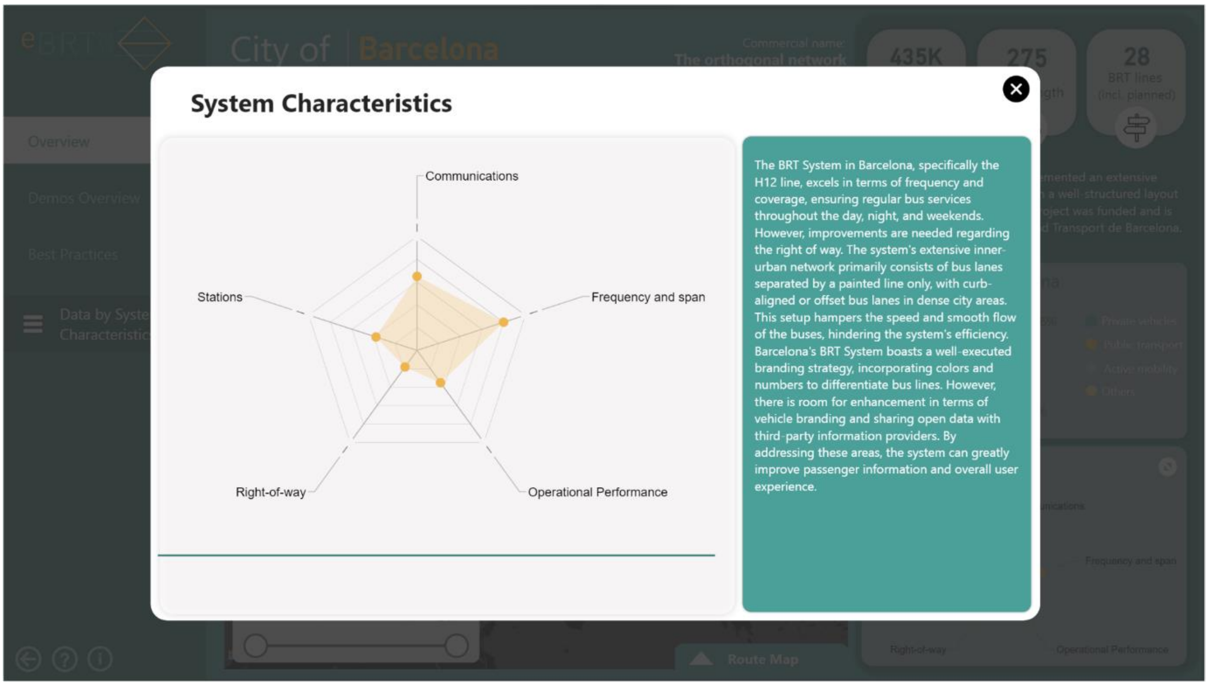


Figure 25. Dynamic mapping. Characteristics of the system

<u>Best Practices</u>

Recognising the value of best practices in system development and improvement, the map will incorporate a section dedicated to highlighting best practices for each of the system characteristics. This makes it easy to find detailed information for specific aspects of the BRT system. Users will be able to explore these systems through descriptive texts, images, and, when possible, contact information. The actual clustering and evaluation of the best practices will take place once the data collection is completed.

<u>Demo Information</u>

The dynamic map capitalises on the close monitoring of the project demos throughout the project execution. Users can delve into the motivations behind implementing the BRT system in the demo cities, understand the impact on the urban environment, identify barriers encountered, and highlight the strengths of each demo use case.

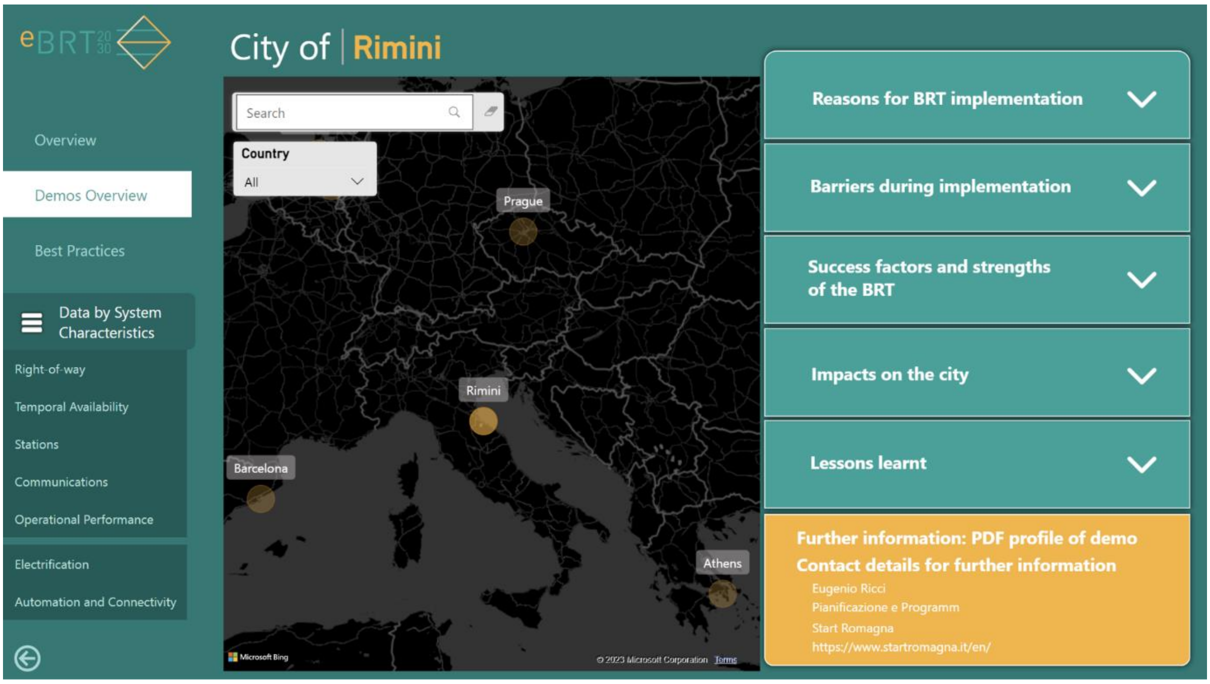


Figure 26. Dynamic Mapping. Example of Rimini demonstration

The dynamic map will be continuously updated throughout the eBRT2030 project to ensure its accuracy and relevance. This will include regular updates on the information on existing BRT lines worldwide. The map will incorporate data from established BRT systems, obtained through various sources such as interviews, reports and collaborations, to provide the most up-to-date insights. Furthermore, the dynamic map will also include information derived from different eBRT2030 work packages. As the project progresses and new findings emerge, relevant data and insights from the eBRT work packages will be integrated into the map. This will ensure that the map reflects the advancements, methodologies, and guidelines developed within the eBRT2030 project itself, enriching its value as a reference tool aligned with the project's objectives.

The map will be published on the project website: https://ebrt2030.eu/

7 DEMO CITIES IN EBRT2030

The eBRT2030 project will demonstrate innovative solutions in six European cities and one international city, namely Barcelona (Spain), Amsterdam (The Netherlands), Eindhoven (The Netherlands), Athens (Greece), Rimini (Italy), Prague (Czech Republic), and Bogota (Colombia). This section presents the different characteristics of the use cases.

Barcelona

The Barcelona eBRT line will run and demonstrate the “Spanish livery” of the European eBRT concept, connectivity, and high-level service. This BRT line will be the upgrade of the heavy-demand diametrical bus route H12 (28.000 pax on working days) that crosses the city and serves the downtown, running on a high-density traffic corridor. It is interconnected with several premium bus routes, metro lines, tramways and regional railways. The bus priority management technology that will be implemented at several intersections will ensure regularity and increase commercial speed.

Figure 27. Barcelona Line H12
© TMB Flickr via Visualhunt

The 21 articulated high-capacity e-buses will be equipped with IoT (internet of things) sensor technology onboard that feeds the bus operator’s big data analytics developments. Strategic bus stops will have IoT sensor technology to capture their activity and user behaviour feeding the big data analytics too. The demo will achieve further efficiency by integrating smart charging and management systems with energy efficiency improvements foreseen.

Charging in the bus depots will be done with smart and modular depot chargers with 50-150 kW units with the latest OCPP (open charge protocols) and smart charging that manages maximum energy at the depot through the bus loading process according to departure times. Two double enroute opportunity charging stations at the terminals will power the articulated electric buses during recovery times.

Amsterdam

The Amsterdam eBRT Demo (line 300) is based on the implementation of an eBRT in the densely populated city of Amsterdam. The eBRT line 300 is running between Amsterdam, the nearby city Haarlem and Schiphol Airport, on dedicated infrastructure with priority at crossings.

With the whole country fast scaling up bus electrification, the demand for electric energy is increasing and power grid facilitating the demand is reaching its limits, and network providers cannot deliver the required grid connections and capacity to support the EBRT operation at preferred locations under normal operating conditions.

To increase the robustness and cope with the grid limitations, an innovative solution will be demonstrated at the bus depot by linking the grid connection to a large-scale stationary battery buffer system of 1MWh (megawatt-hour) and connect the charging infrastructure to a load management system that uses energy from the buffer and the grid connection.

This new storage facility will showcase to which extend peak shaving, combined with energy storage, can contribute to solving the network capacity limitations, by using innovative a new hybrid charging system and smart control units, and a new Open Charge Point Protocol (OCPP) as standalone system unit to minimise the peak power demand. An advanced IoT monitoring platform based on AI will be introduces to estimate the SoC and energy consumption and to optimise the charging process, resulting in lowering the charging trips to the depot by 25% per day and saving up to 5% in charging energy.

Eindhoven

In the eBRT2030 project, the dedicated BRT-line will be located in the Meierij (North Brabant East). In addition, it was recently announced that 20 Zero Emission (ZE) public transport buses will be introduced in the town of Uden. Therefore, the innovations of this project will be implemented in that region as well.

The demo in the Eindhoven region focuses on innovation related to charging infrastructures and energy management within battery status and charge. During the eBRT project, project partners will focus on preserving battery life by always charging the battery at the right speed and the right temperature with bi-directional charging. Simulations have shown that a >20% battery life is realistic in this scenario. Moreover, we will create an interregional BRT line which will cover 250km road. Advancing the BRT-line in the Eindhoven region should help to fight traffic bottlenecks and drastically reduce travel time. Therefore, it is planned to make use of dynamic bus lanes which can be used in both directions, depending on the current traffic situation and timetable. This will ensure a reliable operation, optimal use of the available space and infrastructure, and a comfortable journey for our drivers and passengers.

Moreover, the demo will implement off-vehicle fare payment. By letting customers check in and out their smartcard, bankcard or phone at the stops, it is possible to reduce dwell times, increase average speed and reliability. All-in all, the case of Eindhoven EBRT line will offer approximately 7 million electric BRT km’s on a yearly basis serving travellers during broad opening hours. Applying all the above-mentioned innovations to the eBRT will help to offer an even more sustainable transport solution in terms of asset management, energy usage and traffic congestion.

Athens

This demo will see the revive and upgrade of a BRT-like express bus line (former X14 bus line) operated in the same corridor and following a BRT service concept during the Athens 2004 Olympics.

The Athens eBRT line will showcase a hybrid charging concept, which will exploit existing trolleybus catenary combining typical, depot charging e-buses, trolleybuses and e-buses capable of using trolleybus catenary for opportunity charging (hybrid EBRT buses), using on-board chargers and pantographs.

The line will connect the Fix metro station in the Athens downtown area and the Stavros Niarchos cultural centre, next to the Athens coastline (Athens Riviera), and will have a length of 4 km per direction. The line will operate along Syggrou corridor, a four-lane urban freeway.

The core demo will focus on innovations mounted in hybrid eBRT buses, which will also include improved, multi-phase energy efficient traction motor, optimised power charging management software, tailor-made for catenary-based charging, lightweight battery box. From a service perspective, innovations will consider and exploit the options of 5G based connectivity IoT between vehicles and the eBRT control centre, a sensor-based system for passenger presence/counting in stops. This will allow skip stopping operations and a set of specially designed digital twin and data driven systems for combined operations and power consumption planning, based on different parameters such as the weather, expected loads and so on.

Rimini

Rimini's eBRT line called "MetroMare" will be the backbone of the future structure of sustainable mobility along Emilia-Romagna coastline. Currently it connects the bus terminals near Rimini and Riccione railway stations in about 23 minutes with fully electric trolleybuses making 15 intermediate stops. The BRT line section has a length of 9.8 km, partly with a double lane and partly with a single one and is serviced with 18m full electric trolleybuses.

Figure 28. Rimini MetroMare eBRT © START

The demonstration will improve the "MetroMare" line by an efficient program of predictive maintenance based on an ITS system and data input from onboard and offboard sensors and transferred via LTE/5G or Wi-Fi along the track or in the depot.

Through the predictive maintenance an improvement of 10% on battery life and close to 5% in total cost of ownership (TCO) reduction is expected. In addition, an active safety system and a real time passenger counting onboard and at every stop to trim service scheduling according to real service demand will be linked to the control centre. Finally, through its interconnection with main bus routes and railways, an integrated charging hub concept at the terminal and parking sites along the main stops will be demonstrated and linked as charging service information (for e-cars and e-bikes) into existing Mobility as a Service (MaaS) app.

Prague

The Prague EBRT line will demonstrate In-Motion Charging of double articulated battery trolleybuses in the high demand bus line No. 119, which connects Vaclav Havel Airport Prague to the nearest metro station "Nádraží Veleslavín". The key challenge of this demo is the efficient combination of In-Motion Charging section operation (trolleybus mode) and unwired section operation (battery mode) with possibility of opportunity charging at terminals and at the depot. The goal is to decrease the ratio of wired section to approximately 55-60% and also to allow an unwired connection between depot and bus line.

Bus line No. 119 is now operated by articulated diesel buses (Euro V and Euro VI). It is one of the busiest bus lines in Prague (before COVID19 in 2019 there were 20.000 pax/day). As such, there is the need to increase the bus line capacity to satisfy passenger demand, to increase operational and energy efficiency and decrease environmental impact of bus operation.

As key objective the demo seeks to achieve a sustainable zero emission operation at this high demand bus line using high-capacity vehicles Furthermore, it will look to optimise capital and operation costs as well as the battery lifecycle through an improved energy management on charging power and charging time.

Bogotá

The Bogotá eBRT2030 demo aims to evolve its central axis of passenger transport into a truly sustainable, efficient and safe mobility system. The provision of new BEV feeder buses and their proper integration in the Transmilenio's fleet management and operation system will be complemented by the development and deployment of smart tools and added value services aimed at guaranteeing the optimum operation of the eBRT system in Bogotá.

In particular, safety will be addressed via the latest advanced driver assistance systems (ADAS) and new services onboard to anticipate vehicle manoeuvres and enhance the situational awareness on the e-bus environment, increasing vulnerable users' protection and passengers' safety. In terms of efficiency, ITS solutions will be developed to optimise operation in combination with training support to improve e-bus driving quality and user's comfort.

The Bogota EBRT innovations will address fleet management, including the provision of information for control centres and bus drivers and innovative services with added value for PTOs. The dynamic priority management services to be developed at some intersections will optimize the operation and punctuality of the e-buses.

Energy efficiency during vehicle operation will be optimised by developing added value services to integrate real-time information coming from onboard e-bus sensors, signals/systems, and the infrastructure. At depots, innovative smart charging solutions for large fleet charging management will be provided, optimising the power supplied to the e-buses based on the priorities and restrictions set by the operator, grid requirements and electricity cost.

The table below summarises the common goals of all the European demonstrations as well as the specific objective of each demo.

Table 9. Main goals of eBRT in the six demonstrations

CITY	GOALS
Common goals to all demonstrations	• Decarbonise public transportation by reducing greenhouse gas emissions. • Increase public transport capacity. • Reduce cost/km/passenger and travel times. • Improve customer experience. • Reduce traffic congestion.
Amsterdam **Line 300**	• **Connect dense residential areas** to commercial and business spaces and plan urban, housing and mobility developments together. • **Improve inter-urban and sub-urban public transport** in an **affordable, flexible and adaptable way.**

		• Alleviate the pressure of e-mobility on **the grid and test smart charging.**
Athens **eBRT on Syggrou corridor**		• **Feed the metro** and **connect public transport modes**: metro (north) - tram network (south). • Improve **access to touristic and high public interest points (**Stavros Niarchos Cultural Center, Stavros Niarchos Park, Athen's coastline). • **Test electromobility** and the hybrid charging of e-buses using existing trolleybus catenary and depot charging. • **Test eBRTs ahead of the upcoming Strategic Transport Plan** of Athens. • **Build from previous BRT-like experiences:** the segregated Olympic lanes in 2004 and the current bus expressway lines to the airport.
Barcelona **Premium lines**		• **Support the bus network renewal** (hierarchical structure of bus lines) and the goals of the Barcelona Mobility Plan based on an easier to use, more accessible and faster public transport system. • **Increase network efficiency** by improving multimodality, using fare integration and increasing capacity. • **Improve metropolitan connection**: link badly connected suburban areas to the city through a quick and efficient solution. • **Premium line H12 specific goal**: test an eBRT line, further demonstrate the electrification of bus fleets and improve regularity, reliability, speed, information and intramodality.
Eindhoven North Brabant **eBRT Eindhoven to Meierij area**		• **Greater regional connection:** introduce a main high-capacity public transport mode connecting cities in the province. • **Fill the gap of insufficient public transport** in a wide inter-urban area due to the lack of railway network and **reduce the reliance of the car**. • **Create mobility hubs** with eBRTs being a key mode. • **Connect urbanisation plans and the transit-oriented development** of the province. • Connect the wider province to the **eBRT in the City of Eindhoven.**
Prague **Line 119**		• **Introduce a temporary solution** before the extension of the metro to the high-demand and highly frequent suburban bus route that connects the Nádraží Veleslavín metro stop to the Vaclav airport. • **Reduce impact of the line** by replacing diesel buses with electric buses

	• **Increase the capacity** of bus line 119 which already incorporates BRT elements including dedicated lanes and high frequency. • **Test the BRT concept** as one solution amongst many identified by the city.
Rimini **MetroMare**	• **Improve mobility options, service and capacity** along the coast for tourists and locals and develop a **metropolitan mobility system** by extending the existing MetroMare. • **Increase multimodality in and between Riccione and Rimini:** 3 train stations (Rimini, Riccione, Miramare), 1 airport (Rimini), 2 bus hubs and 2 shared mobility hubs. • **Develop hand-in-hand mobility, urban development and tourism:** the MetroMare is part of the "Piano Strategico" (Strategic plan) of the city and the development of the "Parco del Mare".

As outlined in the previous chapter, the dynamic mapping will provide a comprehensive overview of each demo use case as well as additional information such as reasons for implementation, challenges, success factors, impact over the city and lessons learned.

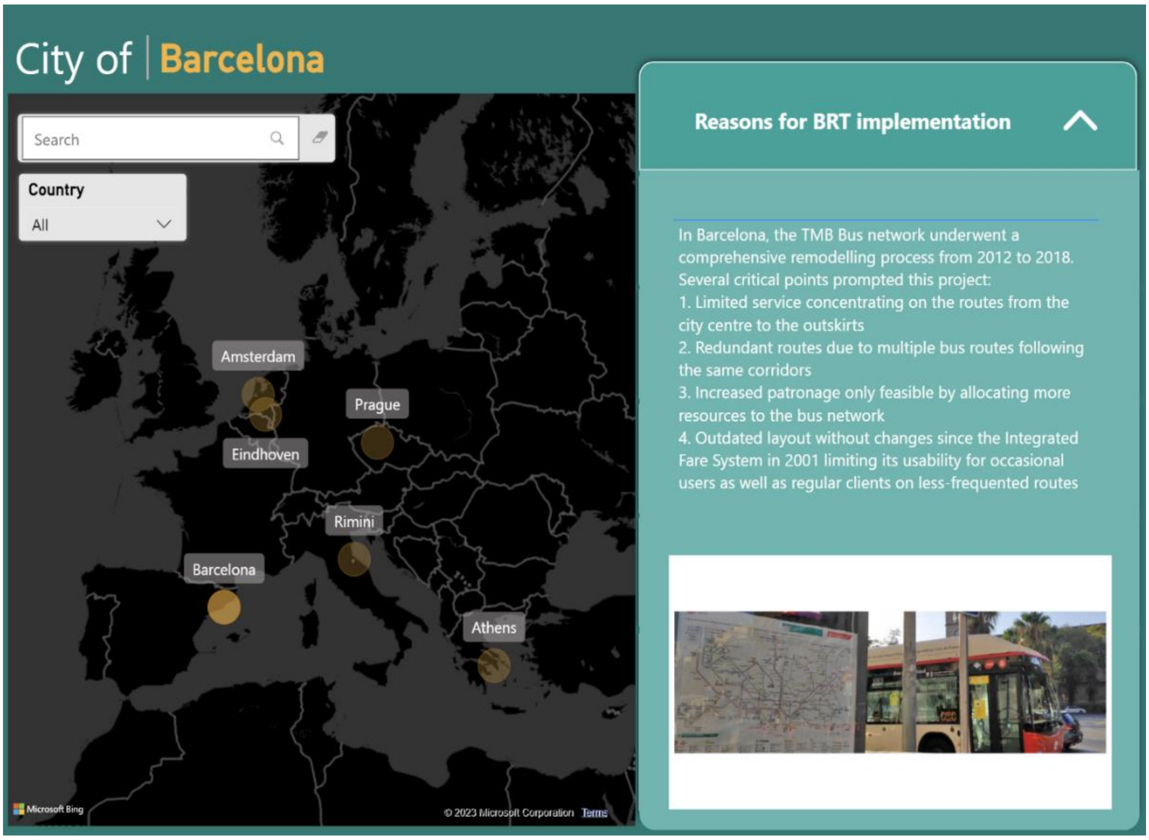


Figure 29. Dynamic mapping. Example of Barcelona

8 GOVERNANCE SUCCESS FACTORS IN BRT IMPLEMENTATION

This report outlined how in recent decades, BRT systems have been implemented worldwide gaining recognition as a cost-effective and high-capacity mobility solution. Now, they are starting to make their mark in Europe as well. With no clear guidelines on how to adapt the BRT concept to European cities' layouts and challenges, they are being conceived and implemented by cities and regions in diverse forms to cater their mobility needs.

To implement eBRTs, local and regional authorities are adapting their institutional, operational, contractual and strategic structures. They are working in intricate political and technical environments that require mobilising multiple levels of governance, actively engaging with the public, coordinating with the private sector and conceptualising the role of eBRTs. In addition, cities and regions are prioritising the decarbonisation of public transport, driving them to integrate electric buses in the implementation of BRTs. The electric component adds a layer of complexity for public authorities and operators. They need to address challenges linked to electrification including charging infrastructure, grid capacity and service reliability.

This chapter is based on interviews conducted both with the public transport operators, and with public transport authorities, regions and/or local governments of the six European demonstrations of the project.

8.1 MULTI-LEVEL GOVERNANCE: THE KEY TO IMPLEMENT A NEW TRANSPORT OPTION

A first common element identified in the implementation of European eBRTs is the need for multi-level governance. These are complex interactions amongst local, regional, national, and international public authorities and bodies. This happens horizontally – municipalities working together on a new inter-urban bus line - and vertically – municipal and regional authorities working together to build a regional transport network, while collaborating with national authorities – for example. These relationships are essential to create public transport systems that are cohesive and connect spaces together beyond administrative boundaries. Through the interviews carried out with the eBRT2030 demonstrations, many examples of such multi-level governance arose.

> In Rimini, the state administration funded 60% of the MetroMare, while the remaining 40% was financed by local and regional authorities. The key political backing from subnational authorities was facilitated by the "*Patrimonio Mobilità Provincia di Rimini*" consortium, a regional entity comprised of 17 municipalities from the Rimini province, two municipalities from the province of Forlì-Cesena, and the municipality of Tavoleto from the neighbouring community of Pesaro-Urbino.

Depending on the city, region or country, Public Transport Authorities (PTAs), local or regional governments are tasked with planning, regulating, managing and/or overseeing the provision of public transportation. Although these responsibilities are often delegated to a PTA, in some cases, the local or regional governments "acts" as a PTA.

The figure below shows how bus system planning can concretely look like, and it identifies three different levels of planning, strategic tactical and operational. Bus system planning is the exercise of preparing the bus service supply to meet a targeted level of service, within a fixed budget and a specific timeline[54].

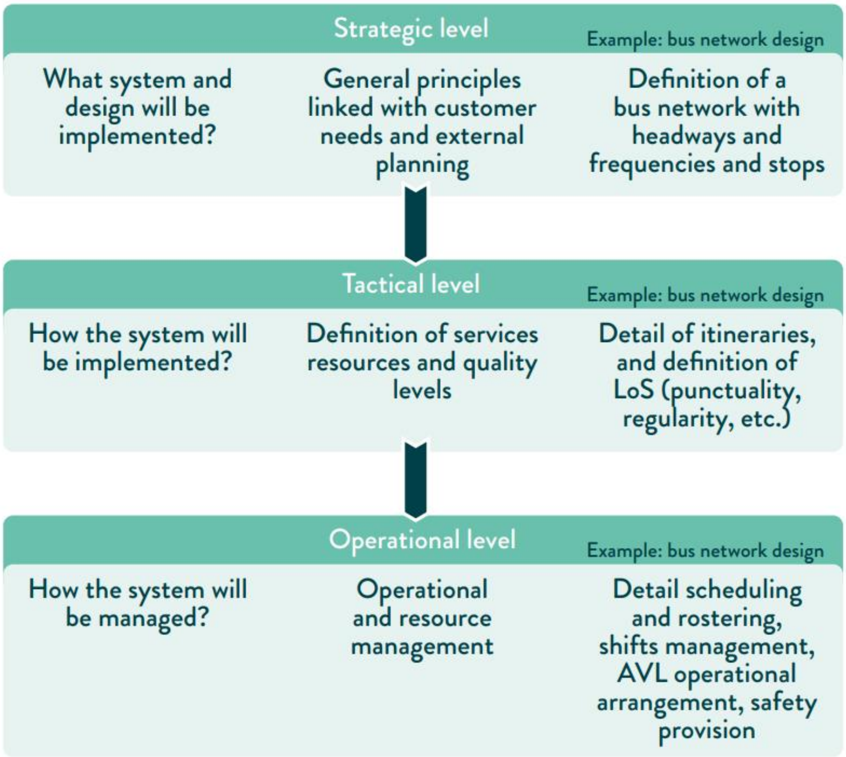


Figure 30. Bus network levels of planning (UITP 2022)

Strategic planning typically falls under the responsibility of the public transport authority or regulator, as it focuses on establishing overall planning principles and ensuring that the bus service effectively meets the transportation needs of citizens. In contrast, tactical and operational planning primarily lies within the domain of bus operators, as it involves scaling down the network planning requirements to specific aspects such as vehicle routes and driver rostering. However, it is important to note that the level of involvement of operators and authorities in tactical and operational planning varies significantly depending on the local context. This variance can be observed worldwide, as different degrees of regulatory agency intervention in these planning aspects are scattered across different regions.[55]

[54] Bus network planning from the operators' perspective (UITP 2022).
[55] Bus network planning from the operators' perspective (UITP 2022).

Table 10. Public governance of eBRTS in the 6 demonstrations

CITY	RIMINI	AMSTERDAM	EINDHOVEN	PRAGUE	BARCELONA	ATHENS
Main Public Body in charge of eBRT	AMR (Agenzia Mobilità Romagnola)	Vervoerregio Amsterdam	Province of North Brabant	ROPID (Regional Organizer of Prague Integrated Transport)	Barcelona City Council	OASA (Athens Urban Transport Organisation)
Sub-national level and nature	Regional PTA	Regional PTA	Regional public authority	Regional PTA	Local public authority	Local PTA

These public bodies work closely with Public Transport Operators (PTOs) that assume significant and diverse responsibilities including service provision, fare collection, scheduling, customer service and more. Regardless of whether these operators are public or private entities, they generally have a contract with the PTA/public entity to deliver public transportation services.

In **Amsterdam and Eindhoven North Brabant,** the PTOs are **private entities**. In Eindhoven North Brabant, the PTOs win a concession for a specific area through a tender process. They have a net cost contract: they receive a lump sum subsidy provided by the local or regional authority and the right to collect passenger fares. Due to this type of contract, the region translates its goals through the PTOs' contract clauses, such as the requirement of using electric buses.

Planning for sustainable urban mobility supports the development of integrated and long-term visions. Plans are public policy instruments that translate ideas into concrete actions and allow a continual effort to reach the established objectives. These include Sustainable Urban Mobility Plans (SUMPs), climate plans, strategic urban development plans and more. The integration of eBRTs into these plans showcases their role in fostering sustainable, reliable, and efficient public transport networks.

8.2 EBRT AS A MEAN TO IMPROVE NETWORK INTEGRATION AND MULTIMODALITY

Integrating eBRTs with other transport modes is critical for their success. They can play many roles in the transport network. Firstly, eBRTs can **transform a mobility landscape to take a central position in an area.** Secondly, eBRTs are used to **reinforce the multimodality of public transport systems**. The adaptability and flexibility BRTs bring in terms of route planning and service demand facilitates transfers for users. Thirdly, eBRTs can **improve an existing bus network**. Their high frequency and high-capacity features often represent an upgrade for high-demand routes, and the reliability coming from having segregated or priority lanes make it easier to switch to other modes. Finally, they can **connect inter-urban areas** together, which is not a function that has been often associated with eBRTs.

8.2.1 USER NEEDS AND PUBLIC ACCEPTANCE

8.2.1.1 Utilising pilots and gradual implementation for a successful scale-up

For successful implementation of eBRTs, public authorities can use **pilots or small-scale and gradual implementations** to assess its acceptance, benefits, value, etc.

These pilots serve as valuable opportunities to showcase the benefits of eBRTs to the general population. Most users support the implementation of eBRTs and are satisfied with them, as the interviews demonstrated. However, the interviewees also shed light on the (potential) **contestations and barriers raised by users** and other stakeholder to their BRT projects. These include:

1. Reluctance from users to change their habits and behaviours.
2. Resistance in changing existing bus networks such as modifications to bus routes and stops, or the suppression of routes to prioritise BRT ones.
3. Opposition from groups including taxi associations who may be affected by the reallocation of space.
4. Conflicts around the change of urban space to make space for eBRT lines which may involve the destruction of buildings.
5. Presence of NIMBYs (Not in My Back Yard) by citizens that support the mobility project but oppose its proximity to their homes.

As part of eBRT2030, the **Athens** demonstration will implement an eBRT line for six months through a temporary permit. The evaluation of this line will have a decisive role in the elaboration of the next Strategic Transport Plan of Athens. OASA took the decision to do the pilot on the Syggrou corridor, a four-lane urban freeway, to increase the likelihood of public acceptance because segregating a lane there would have a minimal impact on the traffic.

In addition, sometimes **internal** or **political obstacles within urban authorities and PTOs** might arise**.** Staff members may be reluctant to develop (e)BRTs, electrify public fleets or deviate from the status quo. These reactions can be due to a gap in the capacity, experience and expertise of these stakeholders in implementing eBRTs and/or e-mobility. Moreover, the eBRT can be a source of political tension but in most cases, eBRTs receive strong political support.

8.2.1.2 Public participation and stakeholder engagement to ensure project ownership and acceptance

A key tool to address contestations or opposition to a public transport project is **public participation** and **stakeholder engagement**. Involving the public in the establishment of public transport networks is essential for reasons that go well beyond acceptance. Public participation is crucial to enable **inclusive decision-making**. Users know their needs best, and they should have a say in the creation of networks. A diversity of opinions, concerns and ideas should be heard and, where applicable, included in the projects to reach inclusive and equitable outcomes. Feeling part of the process will improve **project ownership and acceptance**. As stated previously, users might have negative considerations that can be mitigated through workshops, information sessions, face-to-face on-street surveys, and interviews. Finally, as public transportation projects are designed for public needs, transport planners should be **transparent and open** on the development of their projects to ensure accountability and public trust.

> To implement **Barcelona**'s premium lines, the Barcelona City Council and TMB used an extensive participatory process. Through citizen councils, advisory and neighbourhood mobility committees, ideas and recommendations were gathered and integrated into the network. Users voiced their priorities which included reducing waiting and commuting times. They also helped shed light on issues with the previous network, claiming that it was slow, not accessible, unreliable and inefficient. According to surveys undertaken after the implementation, users stated that the premium lines made the bus network easier to use, more efficient, more accessible, faster and enjoyed the higher capacity.

9 TOWARDS THE EUROPEAN EBRT CONCEPT FOR ALL

This current document is meant to serve as a starting point of the set-up and the development of the eBRT conceptual stream of work and related innovation content for the entire eBRT2030 project. It **outlines an initial framework and set of concept elements that will be tuned, refined and expanded upon as the project progresses over time**. The insights and concepts articulated in this document provide a backbone for subsequent project deliverables and, serve as basis of reference against which key future milestones will be framed, contrasted and validated. As the project evolves**, this document will keep on serving as permanent point of reference and guide for driving the direction and sounding the scope of the work**, ensuring that the final targeted outcomes are comprehensive, informed, and aligned with the goals and objectives of the European concept of BRT in 2030.

In order to develop the European BRT concept for the next step, the **benchmark tool and scorecard method provided will be utilised in the project to measure and calibrate the impact and progresses**. At the same time, the innovation delta of this project in terms of technology will be incorporated in a second, updated version of the scorecard to be released at the end of the project integrating the innovation clusters' key elements of zero-emission fleet operations, connectivity and automation. Electrification is a crucial aspect of modern, net zero transportation systems, and by incorporating it into the scorecard, the project aims to evaluate the feasibility and benefits of adopting electric buses within the BRT scenarios. Similarly, the integration of automation and connectivity functionalities and technologies will be explored, as they have the potential to enhance operational efficiency including the maintenance operations and passenger experience. Furthermore, the European interlocal, peri-urban and suburban landscape will be analysed at a later stage of the project and integrated into the vision for the European electric BRTs for 2030 and beyond.

Finally, the dynamic mapping of BRT systems deployed in Europe developed in Task 2.1 is a powerful tool which will not only facilitate the visualisation of data related to project demonstrations but also display the reach and richness of the eBRT2030 project community.

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