Assessment of innovative measures implemented in European bus systems using key performance indicators

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Abstract This paper reports the results of the assessment of a range of measures implemented in bus systems in five European cities to improve the use of public transport by increasing its attractiveness and enhancing its image in urban areas. This research was conducted as part of the EBSF project (European Bus System of the Future) from 2008 to 2012. New buses (prototypes), new vehicle and infrastructure technologies, and operational best practices were introduced, all of which were combined in a system approach. The measures were assessed using multi-criteria analysis to simultaneously evaluate a certain number of criteria that need to be aggregated. Each criterion is measured by one or more key performance indicators (KPI) calculated in two scenarios (reference scenario, with no measure implemented; and project scenario, with the implementation of some measures), in order to evaluate the difference in the KPI performance between the reference and project scenario. The results indicate that the measures produce a greater benefit in issues related to bus system productivity and customer satisfaction, with the greatest impact on aspects of perceptions of comfort, cleanliness and quality of service, information to passengers and environmental issues. The study also reveals that the implementation of several measures has greater social utility than very specific and isolated measures.

Keywords Assessment of innovative measures · Multicriteria analysis · Key performance indicators · European bus systems

1 Introduction

According to the UITP (International Association of Public Transport), some 80 % of all public transport passengers worldwide are carried by buses, highlighting the major role they play. As a mode of transport the bus has many advantages over railway modes: it is cheap, flexible and can be easily put into service. The bus remains the most widespread solution for achieving sustainable urban development, as it is the only public transport mode in many of the world's cities, and plays a key supporting role in cities with rail transport modes.

Although modes of travel in most developed countries are increasingly dependent on the car (Banister and Berechman 2000), causing a drop in demand for public transport in most industrial economies, the bus remains an important mode of transportation (Jarboui et al. 2012), and is the mainstay of an economy's transportation system. However, since the new millennium, the attractiveness of buses has declined due to declining driving conditions in city centres, buses' negative image (Certu 2005), and because of the considerable difference in service levels compared to modern, efficient and environmentally-friendly trams (Rabuel 2009). The image of bus systems has been even more damaged in urban areas. This trend must be reversed by addressing the issue from a system approach and considering the vehicle, the infrastructure and the operation as part of a whole. This approach first emerged in France in the 2000s under the name of (BHLS) Bus with a High Level of Service, inspired by the American (BRT) Bus Rapid Transit concept but adapted to the European urban context (López and Valdés 2010; Finn et al. 2011; Hidalgo and Gutiérrez 2013). Since then, a number of European cities have applied it to their bus systems, but there is still much to be done to enhance the bus service image.

The EBSF project was part of the European Commission Seventh Framework Programme for Research and Technological Development[1] to design and validate a new ground-breaking generation of bus systems to stimulate European cities to improve their existing services and make public transport more attractive (EBSF 2008). The three main objectives of the EBSF project are: improve bus systems' image; increase bus systems' attractiveness; and improve the competitive position of bus manufacturers and operators. A series of measures were implemented and tested in the bus systems of five European cities (use cases—UC). Key performance indicators (KPI) were defined to measure the performance of different aspects (quality of service, customer satisfaction, urban environment and system productivity) in two scenarios: reference and project scenario.

[1] EBSF was a 4-year project coordinated by UITP (International Association of Public Transport). For the first time, EBSF brings together the five leading European bus manufacturers and 42 other partners including transport operators and national transport associations, public transport authorities, the supply industry, research centers and universities, and consultancy firms.

The aim of this study is to assess whether the implementation of advanced management measures in bus systems—related to quality of service, (ITS) Intelligent Transport Systems, accessibility and maintenance—can improve bus systems' attractiveness, and how far these measures could increase bus patronage. The methodology was based on a multicriteria analysis (MCA).

Following this introduction, Sect. 2 presents a brief summary of existing methods for the assessment of transport initiatives, and the methodology used in the study. The use cases are briefly described in Sect. 3. Section 4 presents the analysis of the results and the discussion. The final section of this article provides the main conclusions of this investigation. An appendix has been added with a more detailed explanation of the UC.

2 Assessment of transport initiatives

2.1 Methods

Several methods are used to evaluate transport initiatives in transport appraisal practice (Tsamboulas et al. 1999). In the last 15 years, the evaluation has included road transport impacts such as safety, pollution and travel comfort, some of which are difficult to measure in monetary terms. It is therefore almost impossible in practice to arrive at totally reliable and widely accepted monetary values (Pearce 1978; Beimborn and Horowits 1993; Bristow and Nellthorp 2000, among others), nor can political priorities be explicitly considered in this type of evaluation.

MCA emerged from the field of operations research (Charnes and Cooper 1961), and evaluates alternatives on a set of criteria reflecting the decision-maker's objectives, ranked on the basis of an aggregation procedure. The scores do not need to be conveyed in monetary terms, but can simply be expressed in physical units or in qualitative terms (De Brucker et al. 2011). Multicriteria decision applications became popular 20 years ago because they could consider a large number of non-commensurable criteria and different alternatives. A number of multicriteria methods has been developed and applied in pursuit of different appraisal objectives in a range of contexts (Bana e Costa et al. 1999). However, not all multicriteria methods are capable of addressing the particularities of transport evaluation, and it is crucial to identify the most suitable method (Tsamboulas et al. 1999).

2.2 Methodological approach

In the present case, a MCA was designed to assess the measures implemented in different bus systems. This approach has been used in a number of transport studies (De Brucker et al. 2011; Delle Site and Filippi 2009; Macharis et al. 2007; Cascajo 2004; among others). In our research this appears to be the best option for simultaneously evaluating a number of criteria, some non-commensurable, to be aggregated. Moreover, MCA makes it possible to work with both quantitative and qualitative criteria.

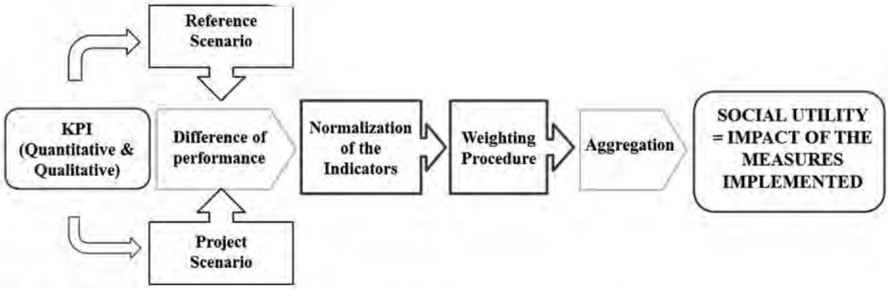

Fig. 1 Evaluation scheme of the measures implemented in bus systems

The scheme of the methodology is shown in Fig. 1 (based on Nijkamp et al. 1990; De Brucker et al. 2004). The evaluation procedure calculates the impact of different measures compared to the existing condition. Thus two scenarios are compared: the scenario without any intervention (the *reference* scenario), and the scenario in which some measures have been implemented (the *project* scenario).

Each criterion is measured by one or more KPI, which are calculated for each scenario. The change in the performance of each indicator is calculated as the relative difference between the two values (always considering that a positive change is an improvement of the indicator and a negative change is a deterioration). It is then necessary to normalise the indicators to standardise the measurement units. The next step is to assign each criterion a weight representing its relative importance to obtaining an innovative high-quality bus system, and all the weighted indicators are aggregated in a final value.

KPI are widely used to measure the performance of an activity (Parmenter 2007). In this investigation, each KPI measures the performance of one aspect of the different bus systems versus the *status quo*. According to Doran (1981), KPI should be SMART, which means Specific, Measurable, Achievable, Realistic and Timely. With this in mind, the KPI for this research were selected according to the project's objectives (improving bus systems' image and attractiveness and the competitive position of bus manufacturers and operators). Figure 2 shows the relationship between the overall project objectives, the evaluation categories, and the areas of investigation. An evaluation matrix was then developed to define evaluation categories, areas of investigation and KPI to measure the achievement of the objectives (see Table 1).

Some of the KPI are quantitative (e.g. commercial speed), while others are qualitative (e.g. perceived comfort level on board). These qualitative KPI rely on assessments, ratings or ranking derived from different surveys (of passengers, drivers and operators). To this end, three questionnaires were designed. The passenger survey was conducted in all the UC, except in Rouen, to capture the perceptions of bus users. The questionnaire for operators was distributed in all the UC to collect service performance data and information on the operation of the bus systems, and this was complemented with a survey of drivers in Gothenburg.

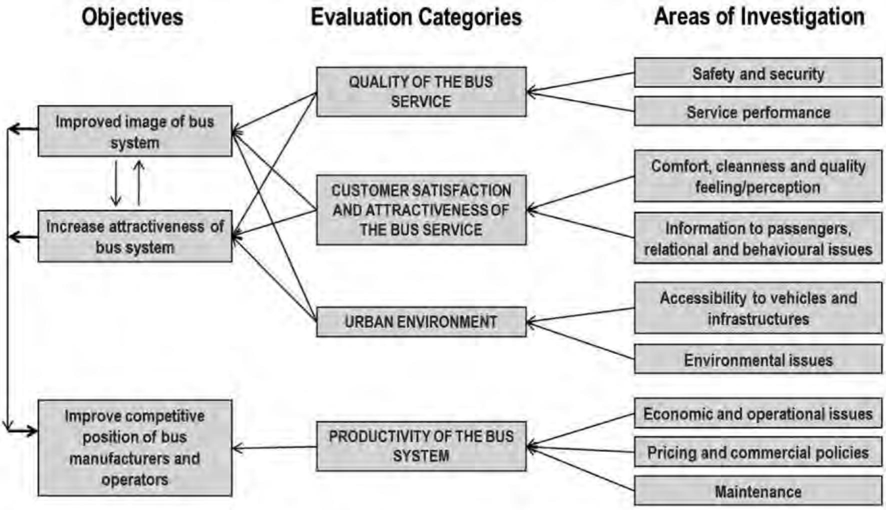

Fig. 2 Relationship between objectives, evaluation categories and areas of investigation

2.3 Passenger survey

The passenger survey was conducted by the authors. It was structured into three parts: (1) trip information; (2) passenger perceptions; and (3) customer profile. Part 2 included questions on some of the KPI: perceptions of safety, quality of service, comfort level on board, and image of the bus system. Each question had a number of items on which the respondents had to note their satisfaction based on a six-point Lickert scale (where 1 is the worst and 6 the best). Table 2 shows the items included in each question of part 2 of the passenger survey.

The passenger survey was conducted in each UC in both the reference and project scenario. The sample size was determined with a confidence level of 95 %. The number of passengers surveyed was above this threshold according to the demand in each UC, with a minimum of 300 valid answers in each scenario. The sample size is described in Chapter 3.

3 Utility functions and weight assignment

The formulation of the process can be written as an additive multi-attribute function (Delle Site and Filippi 2009), as the indicators are normalised by means of utility functions, which assign greater utility to the best performance:

$$U(x) = \sum_{i=1}^{n} w_1 \cdot u_i \tag{1}$$

where:

Table 1 Evaluation matrix

Evaluation Categories	Areas of Investigation	KPI	Units
Bus service quality	Safety and security	Customer perception of bus safety	Obtained from specific passenger survey
		Driver's level of training	Obtained from specific driver survey
	Service performance	Dwell time	S
		Commercial speed	km/h
		Bus punctuality	%
		Bus frequency	Min
Customer satisfaction and attractiveness of bus systems	Comfort, cleanliness and quality perception	Perceived comfort level on board	Obtained from specific passenger survey
		Perceived quality of service	Obtained from specific passenger survey
		Customer perception of image	Obtained from specific passenger survey
	Information to passengers, relational and behavioural issues	Accessibility of real time information (RTI)	% of bus stops equipped with real time information (RTI)
		Availability of information for connecting to other PT services	Obtained from the questionnaire of operators.
		Accessibility to drivers	Obtained from specific driver survey
		Driver's situation	Obtained from specific driver survey
Urban environment	Environmental issues	Energy consumption	L/pass-km
	Accessibility to vehicles and infrastructures	Accessibility for users with special needs	Seconds
System productivity	Economic and operational issues	Operating costs	EURO/km
		Passenger capacity	places-km
	Pricing and commercial policies	Service efficiency	% of operational costs covered by fares
	Maintenance	Technical bus maintenance	Days
		Vehicle failure	Failures in bus/km
		Days in workshop	Days

$U(x)$ multi-attribute utility function of alternative x
w_i weight of the criterion i
u_i individual utility, or single-attribute utility, of the criterion i
n number of criteria

Table 2 Questions relating to passenger perceptions and items included in part 2 of the survey

Q.3. Perception of safety
Q 3.1 Perception of accident risk on board (related to safe driving)
Q 3.2 Perception of accident risk at bus stop
Q 3.3 Perception of the vehicle, is it safe?
Q 3.4 Perception of boarding the bus
Q.4. Perceived quality of service
Q 4.1 Punctuality/waiting time at bus stops
Q 4.2 Bus service operating hours (in terms of service availability)
Q 4.3 Bus service integration with other lines/modes of transport
Q 4.4 Reliability
Q 4.5 Ease of paying fare (on board or at bus stop)
Q 4.6 General quality of bus stops (shelter, seats, lighting)
Q 4.7 Possibility of obtaining information while travelling
Q 4.8 Frequency of service
Q.5. Perceived on-board comfort level
Q 5.1 Quality of driving
Q 5.2 Temperature on board
Q 5.3 Level of noise on board
Q 5.4 Comfort of seats
Q 5.5 Sufficient number of seats
Q 5.6 Cleanness on board
Q 5.7 Provision and visibility of handrails
Q 5.8 State of vehicle maintenance (seats, windows, doors)
Q 5.9 Availability of space and equipment for disabled travellers
Q 5.10 Occupation rate of bus
Q 6. Perception of the bus system's image
Q 6.1 External design of buses
Q 6.2 Internal design and/or layout of buses
Q 6.3 Availability of information services
Q 6.4 Impact on environment (pollution, noise)
Q 6.5 Impact on 'town face' (urban development)
Q 6.6 Innovative character

The utility functions convert the percentage difference of each KPI in a homogeneous value from 0 to 1, which measures the individual utility produced between the scenarios by the change in each KPI.

The multi-attribute utility function, which aggregates the individual utilities in a weighted additive way, thus also has values between 0 and 1. Several authors have confirmed this approach. Jaquet-Lagrèze and Siskos (1981) aggregated the different criteria of each alternative into a single criterion called the utility function. They reported that the additive utility function was the most widely-used form, especially in its linear form of a weighted sum of criteria. Beuthe et al. (2000) and Tsamboulas et al. (1999) established that a linear additive utility function is the most straightforward method of dealing with transportation decision problems. Zietsman et al. (2006) used a method based on the multi-attribute utility theory including both quantitative and qualitative sustainability issues; they also noted the existence of single-attribute utility functions on a normalised scale (0–1) for each criterion.

The shape and thresholds of each utility function were based on the above references, designed by the authors, and discussed by the evaluation working group within the EBSF project. The functions were validated by the partners participating in the project: bus operators and Public Transport Authorities. Five groups of KPIs were defined according to their nature, and a specific utility function was developed for each group. The utility functions have the same direction, i.e. they are all reframed in terms of 'benefit criteria'.

Table 3 shows the KPIs in each group and the formulation of the utility function curves. The five utility functions comprise one or two straight lines, as shown in Fig. 3. The thresholds are calculated based on the difference in percentage in the KPIs between the reference and the project scenario. When there are two thresholds (when the function is formed by two straight lines), the first threshold is the second worst value of the KPI percentage difference between the reference and project scenario of all the results for all the UCs, and the second is the second best value of the KPI change. When the utility function has only one line, there is a single threshold; in this case, this is the second best value of the KPI percentage difference between the reference and project scenario.

The next step in the aggregation procedure is to assign a weight to each area of investigation and each evaluation category to represent their relative importance in an innovative high-quality bus system. Weights are interpreted as the relative importance of the criteria (Jaquet-Lagrèze and Siskos 1981; Nijkamp et al. 1990; De Brucker et al. 2004) and when using additive utility functions the normalisation constraints are as follows (Delle Site and Filippi 2009):

$$\sum_{i=1}^{n} w_i = 1 \, for \; all \; i \tag{2}$$

where w_i is the weight assigned to the criterion i.

The weights were obtained from a specific survey of the different stakeholders[2], and 106 answers were collected. The final weights were calculated as the median of the averages per stakeholder group, and then normalised to fulfil the standardisation requirements shown in Eq. 2.

The global utility is calculated following the method of complete aggregation based on the multi-attribute theory of Keeney and Raiffa (1976). This utility represents the contribution of the measures to an innovative high-quality bus system. The ideal situation would be for all the UC to have all the KPI; however, as different measures were implemented in the different use cases, different areas will

[2] The stakeholders surveyed from different European countries were classified into five groups: transport operators, public transport authorities, manufacturers, university/research centres, and users. Each single stakeholder was asked to rate the different areas of investigation as well as the four categories using a score ranging from 0 to 10. Here, value 10 corresponds to the highest priority in terms of contributing to the development of an innovative high-quality bus system.

Table 3 Utility functions for each group of KPIs

Utility function group	KPIs included	Utility functions
(A) Related to travel time	Dwell time	$y = \left(\frac{0.2}{4}\right)\mathrm{x}, \quad \mathrm{x} < 4$
	Bus punctuality	$y = 0.8\left(\frac{x-4}{9}\right) + 0.2, \quad 4 \le x < 13$
	Bus frequency	$y = 1, \quad x \ge 13$
	Commercial speed	
(B) Related to customer perceptions, driver's perception and mobility behaviour	Customer perception of bus safety	$y = \left(\frac{0.6}{5}\right)x, \quad x < 5$
	Perceived comfort level on board	
	Perceived quality of service	$y = 0.4\left(\frac{x-5}{9}\right) + 0.6, \quad 5 \le x < 14$
	Customer perception of image	
	Driver's level of training	
	Accessibility to drivers	$y = 1, \quad x \ge 14$
	Driver's situation	
(C) Related to costs	Operating costs	$y = \left(\frac{1}{9}\right)x, \quad x < 9$
	Service efficiency	
	Energy consumption	
	Passenger capacity	$y = 1, \quad x \ge 9$
(D) Related to information to passengers	Accessibility to RTI	$y = \left(\frac{1}{20}\right)x, \quad x < 20$
	Availability of information for connecting with other PT services	$y = 1, \quad x \ge 20$
(E) Related to maintenance issues	Technical maintenance of the bus	$y = \left(\frac{1}{90}\right)x, \quad x < 90$
	Vehicle failure	
	Days in workshop	$y = 1, \quad x \ge 90$

x is the percentage difference of each KPI between the reference and the project scenario; y is the individual utility of each KPI, from 0 to 1

be impacted. This implies that not all the UC had data for all the KPI, so the evaluation is made at the level of category and area of investigation with the KPI in each UC.

4 Study context: description of use cases

The solutions developed within the EBSF project have been tested in several European 'showcase cities'. For this paper, we have selected data from five out of seven use cases. These are: Bremerhaven (Germany), Budapest (Hungary), Madrid (Spain), Gothenburg (Sweden) and Rouen (France). Here we present the main characteristics of each UC (EBSF 2012; Cascajo and Monzón 2012). More detailed information on each UC is available in Appendix A.

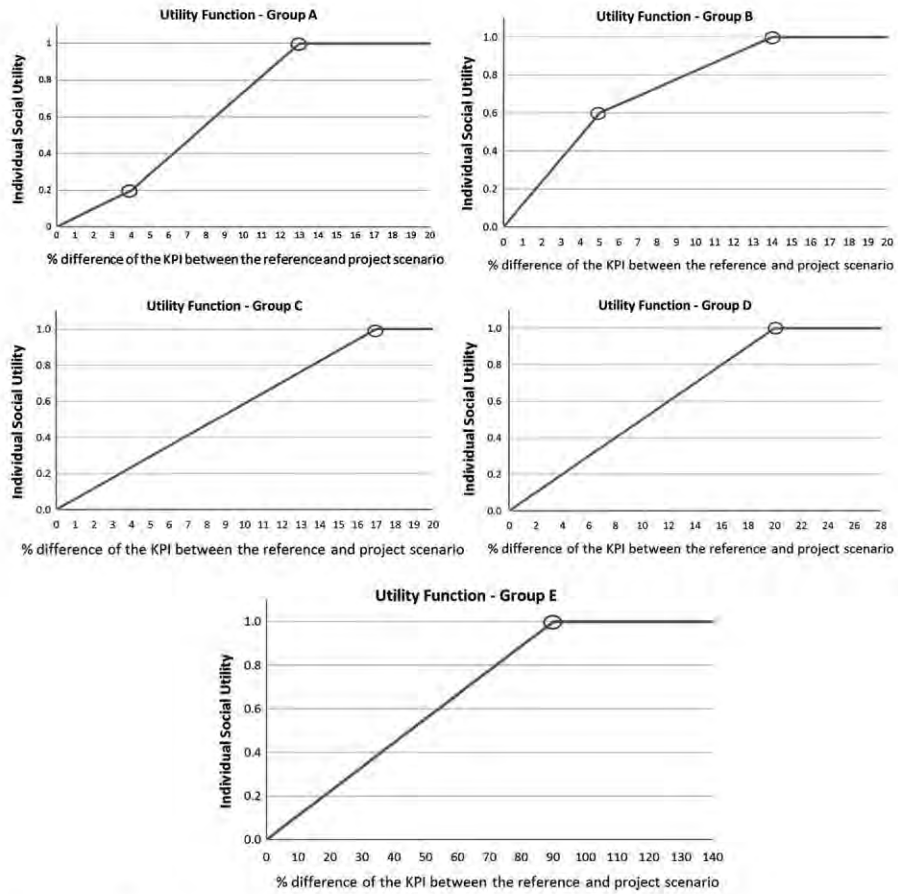

Fig. 3 Utility functions shapes

In Bremerhaven, a number of measures were implemented in bus line 502 to achieve a seamless journey with a high level of comfort, safety, attractiveness, punctuality and standard information, in addition to new ITS systems on board and at certain bus stops. The 502 line runs through the city from north to south and connects the most densely-populated districts outside the central business district and the central station, among others. This line covers 65 % of the population. The fleet of buses circulating on this line comprises 69 Mercedes Benz Citaro articulated vehicles, 100 % low-floor and Euro 4 engine. The test focuses on building a prototype EVOBUS (with an innovative design, detection of occupied seats, etc.) and fitting 15 existing buses with a driver terminal and on-board AVMS with dynamic passenger information computer components for visible passenger information: announcement system and TFT (thin-film transistor) passenger information screens displaying the real departure time from the next bus stops, service interruptions, alternative routes, and tourism- and public-service-related information. Ten strategically-situated bus stops in Bremerhaven were improved with new info terminals displaying public-transport and public-service-related information and constantly updated throughout the day. These info-terminals are an improvement on the existing ones, as they now offer a 22″ screen display and additional communication features such as Bluetooth and (WLAN) Wireless Local Area Network. The test took place between May and December 2011 (7 months), and the sample size of the passenger survey was 400 in each scenario.

One of the objectives pursued in Budapest was to increase the flow of bus passengers while improving comfort, space and security. Another challenge was to improve efficiency in terms of operational costs while meeting environmental protection targets. The main measure for achieving these objectives is the introduction of a new type of vehicle, a 18.75 m MAN Lion City GL articulated bus, which was tested in real operational conditions. This is an innovative urban bus that offers passengers a range of facilities to make journeys as enjoyable and comfortable as possible. It has five doors to ensure a shorter time at stops and offers greater comfort and accessibility for passengers. The bus is specially conceived for large passenger volumes and is equipped with the most innovative systems to guarantee a safer trip (video surveillance of the bus interior and doors, fire extinguisher system in the engine compartment, etc.). The bus also has an environmentally-friendly MAN 320 HP six-cylinder diesel engine designed to reduce energy consumption. It is equipped with a tele-diagnostic system to supply the data measured during service periods, thus helping operators reduce maintenance costs. The use case is line 86, an 11-km inner-city route with high passenger volumes. The test took place between April and November 2011 (7 months), and the sample size of the passenger survey was 400 in each scenario.

The use case of Madrid focuses on the metropolitan bus lines between the municipality of Majadahonda and the city of Madrid. Majadahonda is a town located 18 km west of the city centre. The main objective of the test is to improve the information to users by providing multimodal, real-time passenger information (including buses, trains and traffic) along the corridor, on board the vehicles, at stops and at interchange stations via SMS messaging or the web, Bluetooth, displays, etc. Forty buses from six bus lines were equipped with an AVMS and radio frequency system to ensure underground vehicle location inside the interchange station where the route ends, including on-board screens and an audio information system. Four time-information displays and one Bluetooth device were also implemented at some bus stops in Majadahonda, and one screen at the Moncloa transport interchange hub to provide information on forthcoming departures and breakdowns or delays. The test took place between October 2011 and March 2012 (6 months), and the sample size of the passenger survey was 2,122 in the reference scenario and 2,234 in the project scenario.

In Gothenburg, the measures focused on improving services, accessibility and the driver's workplace. A Volvo demo bus was developed and put in service on route 16, with a central driver's cabin with the first door behind the front wheels and a new internal layout. These features boost passenger comfort, improve accessibility for all and reduce dwell time at stops. Drivers feel safer and have a better view of the traffic situation. Drivers were given a training course in ordinary buses in how to reduce the dwell time at stops, raise the commercial speed and enhance accessibility for all users, and especially for disabled people. The prototype was tested between December 2011 and February 2012 (3 months), and the driver training took place between July and October 2011 (3 months). The sample size of the passenger survey was 300 in each scenario.

The innovations in Rouen focussed on granting easy access for all, including passengers with special needs (the elderly, people with temporary or permanent disability, children, parents with pushchairs, etc.). The test consisted of equipping two Irisbus Iveco buses—a Citelis and an Agora—with optical guidance, and two enhanced systems: an electronic suspension control for vertical gap filling, and a gap filler (a retractable step installed at the second door of an Agora bus) installation for spanning the horizontal gap. The system is linked with a (RFID) Radio Frequency Identification recognition system of the dock for safety, with an RFID transponder installed on the ground just a few meters before the stop, and an RFID reader on the vehicle frame. The gap filler and height regulation systems improve accessibility to the bus, which is an essential condition for encouraging users to choose the bus as their preferred transportation system. The aim was to achieve a generalised improvement in the quality perception of passengers and potential users and promote the use of buses as an accessible mode of transportation for everyone. The test took place between September 2011 and February 2012 (6 months).

5 Analysis of results

5.1 Changes in the KPIs

To see the effects of the actions and how the objectives in each UC have been fulfilled, Table 4 summarises the measures, the key aspects improved with these measures in each UC, the KPIs used to measure the improvements and, finally, the performance of the KPIs in terms of the change (%) between the reference and project scenarios. This is positive if there is an improvement in the project scenario compared to the reference scenario, and negative when the KPI is worse in the project scenario. The table shows a general improvement of all the KPIs, with the exception of one per UC.

In Bremerhaven, the KPIs show an improvement in all cases except energy consumption, with a slight decrease (−2.68 %), which can primarily be attributed to a higher use of air conditioning systems and electronic equipment in the project scenario. In Budapest, the KPIs also show an improvement in the project scenario. Only the users' perception of safety was a little lower in the project scenario (−3.74 %), mainly due to the greater age of the respondents in this scenario than in the reference scenario; this group tends to have a worse perception of safety than younger people. In Madrid, there is a great improvement in the KPI accessibility of RTI (+100 %) thanks to the equipping of 40 buses with an AVMS system, on-board screens and the installation of time-information displays at bus stops, providing multimodal real-time information on board the vehicles or at bus stops, via SMS messaging, web and Bluetooth. However, there is a decrease in the service efficiency indicator due to the increase in the operating costs generated by the new technological devices.

Table 4 Measures per UC, key aspects to improve, and performance of the KPIs

UC cities	Measures implemented	Key aspects to improve	KPI used to measure improvements	% change in KPI
Bremerhaven	– New demonstrator bus with RTI for passenger and communication system technologies	– On-board comfort and safety, attractiveness	Perceived quality of service	13.48
			Customer perception of image	16.00
		– High level of e-public services	Accessibility of RTI	10.64
	– Retrofitting of 15 vehicles with on-board AVMS components	– Passenger information	Information for connecting with other PT services	3.75
		– Public perception		
	– Info-terminals at some bus stops		Energy consumption	–2.68
			Operating costs	0.00
			Service efficiency	0.00
Budapest	– New type of environmentally friendly vehicle (MAN) with 5 doors, and a new interior design	– Shorter journey time	Customer perception of bus safety	–3.74
		– Passenger flow, comfort and spaciousness	Dwell time	13.39
		– Safety	Commercial speed	4.00
	– Telediagnostic system	– Environment	Bus punctuality	51.72
	– Priority at traffic lights	– Remote maintenance	Bus frequency	3.51
			Perceived comfort level on board	7.58
			Perceived quality of service	4.79
			Energy consumption	16.79
			Operating costs	16.67
			Passenger capacity	3.30
			Technical maintenance of the bus	990.91
			Vehicle failure	90.38
			Days in workshop	74.51

Table 4 continued

UC cities	Measures implemented	Key aspects to improve	KPI used to measure improvements	% change in KPI
Gothenburg	– New bus demonstrator (VOLVO) with central driver cabin, double doors and folding seats – Driver training	– New driver position – Passenger accessibility – Commercial speed	Customer perception of bus safety	3.71
			Driver's level of training	9.96
			Dwell time	6.06
			Commercial speed	0.00
			Bus punctuality	5.80
			Perceived comfort level on board	24.63
			Perceived quality of service	4.21
			Customer perception of image	4.19
			Accessibility to drivers	−3.10
			Driver's situation	9.23
			Energy consumption	8.33
			Passenger capacity	7.69
			Service efficiency	9.26
Madrid	– Integrated PT management centre – 40 buses with AVMS and radio frequency system; on-board screens, audio info; time-info displays at stops and 1 screen in Moncloa interchange	– Passenger information – Advanced traffic management – Real time multi-modal information – Underground location of vehicles	Bus punctuality	3.23
			Perceived quality of service	5.57
			Accessibility of RTI	100.00
			Information for connecting with other PT services	20.34
			Service efficiency	−1.05
Rouen	– Installation of two devices for reducing both vertical and horizontal gaps in two existing vehicles.	– Easy boarding/alighting for all passengers – Accurate docking	Commercial speed	0.00
			Energy consumption	−12.05
			Accessibility for users with special needs	8.89
			Operating costs	0.00
			Passenger capacity	0.00

Table 5 Results for Bremerhaven and Budapest

Bremerhaven

Evaluation categories	Areas of investigation	Name of KPI	% Change in KPI	Utility function group	Changes in		Weights		Social utility improvements	
					Utility per KPI	Utility per category	Per category	Normalised per category	Per category	Total
Customer satisfaction and attractiveness of bus systems	Comfort, cleanliness and perception of quality	Perceived quality of service	13.48	B	0.98	0.67	9.03	0.38	0.26	0.26
		Customer perception of image	14.31	B	1.00					
	Information to passengers, relational and behavioural issues	Accessibility of RTI	10.64	D	0.53					
		Availability of information for connecting with other PT services	3.75	D	0.19					
Urban environment	Environmental issues	Energy consumption	−2.68	C	0.00	0.00	7.00	0.30	0.00	
Productivity of the system	Economic and operational issues	Operating costs	0.00	C	0.00	0.00	7.52	0.32	0.00	
	Pricing and commercial policies	Service efficiency	0.00	C	0.00					

Table 5 continued

Budapest

Evaluation categories	Areas of investigation	Name of KPI	% Change in KPI	Utility function group	Changes in		Weights		Social utility improvements	
					Utility per KPI	Utility per Category	Per Category	Normalised per category	Per category	Total
Bus service quality	Safety and security	Customer perception of bus safety	−3.74	B	0.00	0.48	8.79	0.27	0.13	0.72
	Service performance	Dwell time	13.39	A	1.00					
		Commercial Speed	4.00	A	0.20					
		Bus punctuality	51.72	A	1.00					
		Bus frequency	3.51	A	0.18					
Customer satisfaction and attractiveness of bus systems	Comfort, cleanness and quality perception	Perceived comfort level on board	7.58	B	0.71	0.64	9.03	0.28	0.18	
		Perceived quality of service	4.79	B	0.57					
Urban environment	Environmental issues	Energy consumption	16.79	C	1.00	1.00	7.00	0.22	0.22	
Productivity of the system	Economic and operational issues	Operating costs	16.67	C	1.00	0.84	7.52	0.23	0.19	
		Passenger capacity	3.30	C	0.37					
	Maintenance	Technical maintenance of the bus	990.91	E	1.00					
		Vehicle failure	90.38	E	1.00					
		Days in workshop	74.51	E	0.83					

Table 6 Results for Gothenburg, Madrid and Rouen

Gothenburg

Evaluation categories	Areas of investigation	Name of KPI	% Change in KPI	Utility function group	Changes in		Weights		Social utility improvements	
					Utility per KPI	Utility per category	Per category	Normalised per category	Per category	Total
Bus service quality	Safety and security	Customer perception of bus safety	3.71	B	0.44	0.40	8.79	0.27	0.11	0.68
		Driver's level of training	9.96	B	0.82					
	Service performance	Dwell time	6.06	A	0.38					
		Commercial speed	0.00	A	0.00					
		Bus punctuality	5.80	A	0.36					
Customer satisfaction and attractiveness of bus systems	Comfort, cleanliness and quality perception	Perceived comfort level on board	24.63	B	1.00	0.56	9.03	0.28	0.16	
		Perceived quality of service	4.21	B	0.51					
		Customer perception of image	4.19	B	0.50					
	Information to passengers, relational and behavioural issues	Accessibility to drivers	−3.10	B	0.00					
		Driver's situation	9.23	B	0.79					
Urban environment	Environmental issues	Energy consumption	8.33	C	0.92	0.92	7.00	0.22	0.20	
Productivity of the system	Economic and operational issues	Passenger capacity	7.69	C	0.85	0.93	7.52	0.23	0.22	
	Pricing and commercial policies	Service efficiency	9.26	C	1.00					

Table 6 Results for Gothenburg, Madrid and Rouen

Madrid

Evaluation categories	Areas of investigation	Name of KPI	% Change in KPI	Utility function group	Changes in		Weights		Social utility improvements	
					Utility per KPI	Utility per category	Per category	Normalised per category	Per category	Total
Bus service quality	Service performance	Bus punctuality	3.23	A	0.16	0.16	8.79	0.35	0.06	0.37
Customer satisfaction and attractiveness of bus systems	Comfort, cleanliness and quality feeling/perception	Perceived quality of service	5.57	B	0.63	0.88	9.03	0.36	0.31	
	Information to passengers, relational and behavioural issues	Accessibility of real-time information	100.00	D	1.00					
		Availability of information for connecting with other PT services	20.34	D	1.00					
Productivity of the system	Pricing and commercial policies	Service efficiency	−1.05	C	0.00	0.00	7.52	0.30	0.00	

Rouen

Evaluation categories	Areas of investigation	Name of KPI	% Change in KPI	Utility function group	Changes in		Weights		Social utility improvements	
					Utility per KPI	Utility per category	Per category	Normalised per category	Per category	Total
Bus service quality	Service performance	Commercial speed	0.00	A	0.00	0.00	8.79	0.38	0.00	0.12
Urban environment	Environmental issues	Energy consumption	−12.05	C	0.00	0.39	7.00	0.30	0.12	
	Accessibility to vehicles and infrastructures	Accessibility for users with special needs	8.89	B	0.77					
Productivity of the system	Economic and operational issues	Operating costs	0.00	C	0.00	0.00	7.52	0.32	0.00	
		Passenger capacity	0.00	C	0.00					

In Gothenburg, the KPI for driver accessibility did not improve with the new measures; this KPI was obtained from the driver survey, and this can thus be explained by the fact that the drivers surveyed in the project scenario[3] were more experienced and also older than those in the reference scenario. Finally, Rouen saw a decrease in the KPI energy consumption due to the new devices.

5.2 Results per UC and evaluation category

The comparison of KPIs (quantitative and qualitative) between the reference and project scenarios is a means of measuring the social utility of the new measures in different contexts.

The results of the MCA for the different use cases are shown in Tables 5 and 6. From left to right the tables show the difference (in %) in the KPIs between the reference and project scenario, their utility function group, the changes in utility in each KPI due to the new measures, the changes in the utility per category (calculated as the average of the previous changes in the KPI utilities), the weights assigned to each category and their normalisation (fulfilling Eq. 2), and the improvements in social utility per category and the total improvement per UC (on a scale of 0–1). As can be seen, not all the KPIs were measured in the five UC, as the measures were very diverse and impacted different areas of investigation in each UC.

Positive improvements in social utilities between the reference and project scenario mean that the measures enhance the situation in this category; neutral improvements (=0) represent no change between the reference and project scenario; and negative improvements in social utilities show the measure worsened the situation compared to the status quo. The results are analysed below.

In Bremerhaven there is a substantial improvement in the social utility of the category "Customer satisfaction and attractiveness of bus services", which can primarily be attributed to a higher passenger perception of quality of service and image in the project scenario. Also significant are the improvements in accessibility to real time information and information for connecting to other PT services. In Budapest, the category with the greatest improvement is "Urban environment", as a result of the lower fuel consumption of the prototype. This UC is improved in all four categories, showing that the new measures in Budapest impact all aspects. In Gothenburg, as in Budapest, the four evaluation categories improved; the "Productivity of the system" and the "Urban environment" are the categories that were most upgraded in the project scenario. In Madrid, there is a substantial improvement in social utility in the category "Customer satisfaction and attractiveness of bus services", which can be attributed primarily to the increased information available to passengers, who now can access it in different ways and real-time conditions. Users' perception of the quality of service is also a key aspect in this improvement. Lastly, Rouen shows improvement in the category "Urban

[3] The sample of drivers surveyed in Gothenburg in the two scenarios was different because the demo bus needed specialist drivers, with special training in different areas.

Table 7 Changes in utility per area of investigation

Evaluation categories	Areas of investigation (AI)	Weights per AI (from 1 to 10)	Social utility improvements per AI				
			Bremerhaven	Budapest	Gothenburg	Madrid	Rouen
Bus service quality	Safety and security	12.11	–	0.00	**0.08**		–
	Service performance	12.29	–	**0.07**	0.03	0.02	0.00
Customer satisfaction and attractiveness of bus systems	Comfort, cleanliness and quality perception	11.51	**0.11**	0.07	0.08	0.07	–
	Information to passengers, relational and behavioural issues	11.88	0.04	0.00	0.05	**0.12**	–
Urban environment	Environmental issues	10.86	0.00	**0.11**	0.05	–	–
	Accessibility to vehicles and infrastructures	11.18	–	–	–	–	**0.09**
Productivity of the system	Economic and operational issues	10.14	0.00	0.07	**0.09**	0.00	–
	Pricing and commercial policies	9.29	0.00	–	**0.09**	0.00	–
	Maintenance	10.73	–	**0.10**	–	–	–

Bold values indicate the highest improvements in social utility per area of investigation

–: not applicable

environment" owing to the better access provided for users with special needs, in keeping with its objective of improving accessibility.

If we compare the results considering the different types of measures implemented in each UC, we see that Budapest and Gothenburg have the highest improvement in social utility (0.72 and 0.68, respectively); both UCs tested new prototypes in their cities to increase passenger flow and bus capacity, among other issues. Bremerhaven and Madrid focused their studies on ITS measures, showing good improvements in the category of customer satisfaction and attractiveness of the system, thus highlighting the importance of these kinds of measures in improving the image of the system for passengers. The improvements in social utility (0.26 and 0.37, respectively) are lower than for Budapest and Gothenburg. Rouen shows an overall improvement in social utility of 0.12—the lowest of all the UCs—because the measures implemented were very specific and concentrated on only one objective.

5.3 Results per area of investigation

The same MCA procedure is followed to calculate improvements in social utility per area of investigation (see Table 7), using the weights assigned to each area instead of each category. As in the MCA per evaluation category, the weights are also normalised in order to satisfy the requirements of Eq. 2. The table shows the improvements in social utility per area of investigation and UC. In terms of *safety* and *security*, the greatest improvements occur in Gothenburg, with a social utility of 0.08; Gothenburg also presents the highest improvements in two other areas, as compared to the other cities: *economic and operational issues* and *pricing and commercial policies,* with a social utility of 0.09. Regarding *service performance*, the maximum improvement in social utility was recorded in Budapest, with 0.07. Bremerhaven has the highest value for *comfort, cleanliness and perception of quality*, with 0.11. Madrid shows the most significant improvement in *information to passengers*, *relational and behavioural issues* compared to other cities, with 0.12. This value is also the highest in the table. The best value for *environmental issues* was achieved in Budapest, with 0.11. This city also had the best results for the area *maintenance issues*, with 0.10. These results are interpreted and debated in Sect. 6.

5.4 Overall results per evaluation category

The analysis can also be done considering all the measures implemented in the five use cases as a whole, with an overall social utility of 0.61. The improvements in social utility per category range from 0.11 to 0.19 (see Fig. 4). The evaluation category with the highest increase in social utility is 'Productivity of the system'—due to the measures implemented in Budapest and Gothenburg which had the greatest improvement in KPIs relating to maintenance—followed by economic and operation-related KPIs. This is closely followed by 'Customer satisfaction and attractiveness of bus systems', with an improvement of 0.18 in social utility, which is enhanced in four use cases out of five. This indicates that this category improves regardless of the type of measure, and that the technological improvements in the

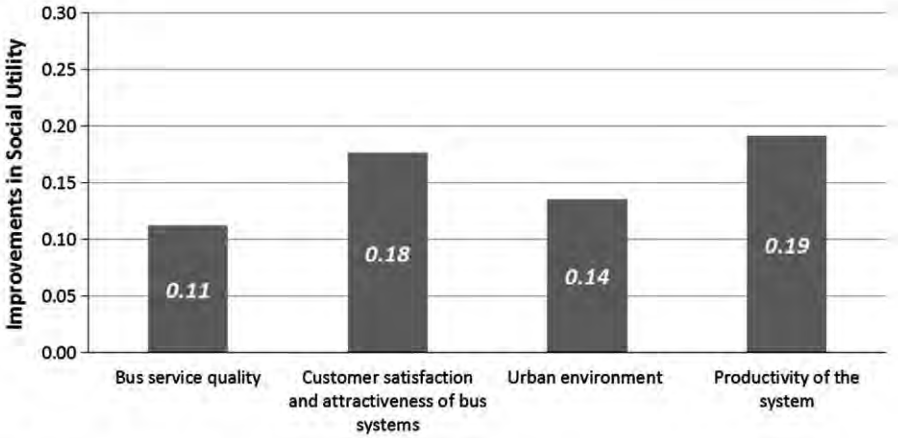

Fig. 4 Improvements in social utility per evaluation category

prototypes are actually perceived by travellers. 'Urban environment' improves its social utility by 0.14, thanks to the significant reduction in fuel consumption in two UCs, and the gains in accessibility for users with special needs in Rouen. In contrast, the least enhanced category was 'Bus service quality', signalling that bus performance improved less than its quality as perceived by the users.

6 Discussion

Overall, the results show that most of the measures tested were successful in improving quality of service, customer satisfaction, the environment and the productivity of the system. They improved the general social utility of the projects, and to a greater or lesser extent depending not only on the type of measure, but also on certain external factors affecting the results—such as the short test periods—suggesting that these issues should be implemented on a city-wide scale and applied to the whole system for a more reliable observation of the changes. The tests were also done on a very small sample size (i.e. one new prototype in Budapest; two buses fitted in Rouen, and one demonstration bus and 15 retrofitted buses in Bremerhaven): a more wide-scale implementation could also have produced more meaningful results.

The results in Table 7 highlight the following points: Gothenburg is the only UC showing a positive impact on *safety* and *security*, with an increase in the users' perception due to the new vehicle, which is viewed as being slightly safer than regular buses. Moreover, the new driver position (central) is seen as being safer and with a better view of the traffic situation. Added to this is the specific training received by drivers to improve their driving and manoeuvring.

In terms of *service performance*, three UCs showed a positive impact: Budapest, Gothenburg and Madrid, where Budapest had the highest improvement in social utility. The new bus layout introduced in Budapest (with five doors) produced a decrease in dwell time and an increase in commercial speed, also influenced by the introduction of a degree of priority at traffic lights. The punctuality of the service improved significantly (51.7 %), and headway was reduced. These effects meet the objectives of decreasing journey time and increasing passenger flow. In Gothenburg, the improvement in service performance was due to the reduction in dwell time, which may be a result of driver training. Madrid improved its punctuality due to the AVMS system, which increased the reliability of the bus services, one of the main aspects to be improved.

Four UCs improved in the area of *comfort, cleanliness and perception of quality*: Bremerhaven, Budapest, Gothenburg and Madrid. Passengers in Bremerhaven noted an important increase in both quality of service and image of the bus system. Information while travelling and quality of bus stops are the items that showed the greatest improvement in passengers' opinion. With regard to the perception of image, the greatest improvements were seen in the availability of different information services during the trip and the innovative character of the prototype. In Budapest, comfort on board and quality of service improved due to the layout of the new bus, and other aspects such as on-board cleanness. A new bus was introduced in these three UCs, and it is clear that this enhanced passengers' perception of quality of service, comfort on-board and image of the bus system. In Gothenburg, the most important issue noted by passengers was the comfort level on board due to the redesigned interior layout of the new bus, with its focus on comfort and accessibility. However, the improvement in this area in Madrid is due to passenger perception of the quality of the service, especially in punctuality (+7 %), information while travelling (+14 %) and frequency of service (+6 %).

Bremerhaven, Gothenburg and Madrid showed a positive impact in *information to passengers, relational and behavioural issues*. Madrid improved the availability of information by different means (web, SMS, displays, Bluetooth) and provided multimodal information on the state of other modes of transport. In Bremerhaven, the equipment introduced in the retrofitted buses and at bus stops led to an increase in the quantity and quality of real-time information for passengers. In Gothenburg, improvements in this area were due to advances in the driver situation with regard to ergonomics and training.

Only Budapest and Gothenburg showed a significant impact in *environmental issues*. The demobus introduced in Budapest is powered by a modern engine that reduces fuel consumption. Fuel consumption also decreased in Gothenburg thanks to the more efficient engine of the prototype. Although this was not a key issue for improvement in this UC, the reduction of dwell time at bus stops led to a reduction in fuel consumption, thus producing benefits for the environment.

Rouen showed an increase in social utility in *accessibility to vehicles and infrastructures* due to improved access by passengers with impaired mobility thanks to the new devices installed in the buses.

Budapest and Gothenburg showed an impact on *economic and operational issues*. In Budapest, the decrease in commercial speed and the lower maintenance of the new bus led to a reduction in operating costs, in addition to increased passenger capacity. In Gothenburg, the new bus produced an increase in passenger capacity as a result of the new layout of the prototype.

Gothenburg showed a benefit in the area of *pricing and commercial policies* due to the increase in service efficiency between the reference and project scenario.

Finally, Budapest saw a positive impact in *maintenance*, mainly as a result of the reduction in the mean time between failures and the decline in the number of days in the workshop. This was possible thanks to the telediagnostic system which provides data measured during service periods, helping operators to reduce maintenance costs.

7 Conclusions

The objective of this paper is to investigate the way the different measures implemented in various bus systems can improve the attractiveness and performance of bus systems and achieve a high-quality transport system. In other words, the aim is to determine the increase in social utility produced by these measures, by aggregating the benefits perceived by the users, the operators and the bus system as a whole. A multicriteria analysis was applied and proved useful for the assessment of advanced measures, as it enables a large number of indicators to be considered that cannot necessarily be expressed in monetary or even physical units (De Brucker et al. 2011).

The analysis of the results shows the success of most of the measures tested. However, their impact depends on the type of measures.

The different internal layouts of the prototypes significantly improved the flow of passengers inside the bus and reduced dwell time. This in turn enhanced other aspects of service performance such as commercial speed, punctuality and frequency. The new prototypes also provided real-time information to passengers, higher on-board comfort levels, lower noise, and a modern external design, which can enhance the general perception of the bus system by both users and non-users. The new engines for these prototype buses are more efficient and less harmful to the environment; they produce fewer emissions and consume less fuel, which may reduce operating costs and increase service efficiency, as in Budapest and Gothenburg.

The implementation of ITS measures in the bus systems appeared to be a key factor for improving the attractiveness of bus systems and customer satisfaction. This confirms the results of other studies (Daskalakis and Stathopoulos 2008; Hounsell et al. 2009; Monzon et al. 2013) which found that these measures are positively accepted by passengers, who perceived significant reductions in the uncertainty of waiting times and the easy access to all kinds of information for planning their journey.

It is very important for operators to optimise maintenance procedures to reduce the budget dedicated to this core activity. The maintenance measures implemented in Budapest positively affected the technical maintenance of the bus, and decreased the mean time between failures; they also reduced the days in the workshop for corrective maintenance and lowered operating costs, thereby improving service efficiency.

Finally, the measures enabling full accessibility for all citizens, regardless of their physical status, are very important to achieving a high-quality bus system. All modes of transport must be accessible to all kinds of passengers, including elderly people, the disabled or parents with prams. This is an essential condition for encouraging users to choose the bus as their preferred mode of transportation.

Generally speaking, although all the measures were implemented in a small number of buses and during a short period of time, passengers clearly noted certain improvements, thereby signalling their considerable potential. These improvements were more evident when a combination of measures was applied as opposed to a single very specific measure on its own. This conclusion was also found in different studies (May et al. 2000; Diab and El-Geneidy 2012).

With regard to the political implications of these improvements, the EBSF project contained an in-depth analysis of the present and future needs of the main bus system stakeholders (users, operators and authorities, bus systems and their components), to develop a new generation of urban bus systems adapted to the specific features of European cities. All the new measures in the different UC improved the overall attractiveness of the bus system, making travelling by bus more appealing, efficient and accessible for all. The findings of this research represent a great opportunity to restore the image of this transport mode in comparison with other modes as well as improving the balance between the bus and other modes, as often proposed by local authorities. Some outcomes could certainly be of interest to authorities in making bus systems more attractive than at present in order to stimulate a transfer of trips from the car to the bus in the medium to long term. The findings can help raise awareness in legislators on certain key issues in bus and public transport.

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