D17.6. Code of Practice for New Design Options of the Exterior and Interior Design and Layout of Buses and its Interface with the Platform

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SUMMARY SHEET

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Abstract	The EBSF 2 project has developed and tested, both in simulations and in field trials, different design solutions for (electric) buses and bus stops as well as the interface between the two. The results show that electrification can have a potentially huge positive impact on comfort, safety, accessibility, as well as the general impression of the public transport system. Simulations show that a number of design details impact efficiency and perception such as: large doors, big open areas around doors, absence of obstructions between door and seat/wheelchair position, etc. Results also demonstrate the importance of considering carefully the interplay between bus design, bus stop design, and e.g. rules for boarding. Simulations are here an important design tool. The EBSF 2 project has furthermore demonstrated the the feasibility and potential of indoor bus stops. Overall, electric buses, almost completely silent and without local emissions, offer new possibilities to progress towards a bus system that is more integrated with the city and everyday activities.
Keywords	Bus system, bus design, bus stop design,

INTERNAL DISTRIBUTION

Participant N°	Participant organisation name	Country
1 Coordinator	Union Internationale des Transports Publics - UITP	Belgium
2	Régie Autonome des Transports Parisiens - RATP	France
3	Iveco France SA - IVECO	France
4	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. - FRAUNHOFER	Germany
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0.3	03/05/2018	Merging of contribution	CHALMERS/CEIT	Design Charter – final release
0.4	16/05/2018	Merging of contribution	CHALMERS/CEIT	San Sebastian demo: final results
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Table of Contents

EUROPEAN BUS SYSTEM of the FUTURE 2

Index of Figures

Index of Tables

1 Executive Summary

A bus system is a transit system consisting of buses, infrastructure in terms of - for example - bus stops, shelters and stations, information services, schedules, routes, ticketing solutions, operational practices, etc. The EBSF 2 project has developed and tested, both in simulations and in practice, a number of different solutions for buses and bus stops, including the interface between the two.

The results of the simulations and field trials show that electrification can have a potentially huge positive impact on comfort, safety, accessibility, as well as the general impression of the public transport system.

Reducing the time-to-target of all passengers is an essential objective when designing new layouts that optimize accessibility and dwell time. The EBSF2 project could show a number of design choices that impact time-to-target positively, such as: large doors, big open areas around doors, absence of obstructions between door and seat/wheelchair position, etc. Here, simulations offer an important design tool.

Traditionally, bus stops have been designed to provide travellers with a landmark indicating where the bus will stop. Today bus stops have also become an important part of the image of the brand for both the operator and the public transport authority. Bus stops with shelters provide travellers with protection from bad weather but could also offer additional services to citizens, whether they are travellers or simply passers-by. However, EBSF 2 results demonstrate the importance of considering carefully the interplay between bus design, bus stop design, and e.g. rules for boarding, Also in this case, simulations offer an important tool for design decisions.

The project has furthermore demonstrated the feasibility and potential of indoor bus stops. A key to the integration between buses, bus stops and city was found to be the location of the stop. With a specific destination (such as a library, a hospital, or a shopping mall) close to the stop, the destination itself can act as a bus stop. Electric buses, almost completely silent and without local emissions, offer new possibilities to progress towards this closeness to the destination, and consequently a bus system that is more integrated with the city.

2 Introduction

The European Bus Systems of the Future 2 (EBSF 2) is an innovation action co-funded by the European Union within the Horizon 2020 Research and Innovation programme and coordinated by UITP – the International Association of Public Transport. The project, which runs between May 2015 and April 2018, capitalizes on the results of the previous EBSF project (2008-2013) and aims, as the former, to develop a new generation of urban bus systems by means of new vehicle technologies and infrastructures in combination with operational best practices, and test them in operating scenarios within several European bus networks.

The need for more cost-effective and energy efficient bus systems has led to the identification of a set of technological innovations (TIs) and strategies with a strong potential to optimize mainly energy and thermal management of buses (in particular auxiliaries such as climate systems), green driver (eco driving) assistance systems, intelligent garage and maintenance processes, IT standard equipment and services. Moreover, to effectively address the need to move quickly from laboratory research to actual innovation of the bus fleets in operation in Europe, the technologies to be tested have been selected according to their technological maturity (and not only because of their potential) in order to ensure a short step to commercialisation once the project ends. The use of simulators and prototypes has been conceived as a preliminary step for the validation of the innovations in real operational scenarios, performed within the project as well, or as a necessary task to prove the potential of more futuristic solutions currently implemented at early stage of development (e.g. modular bus).

2.1 Scope of deliverable

Thus, EBSF 2 aims to test, evaluate and validate innovative technological solutions and/or strategies for urban and sub urban bus systems through demonstrations in real service. The ultimate goal is to improve the efficiency of operations mainly in terms of costs and energy consumption but also to increase the modal share of bus services by improving the image of the bus for the users.

Six key research areas have been identified to have the highest potential to impact:

- Energy Strategy and Auxiliaries;
- Green Driver Assistance Systems;
- IT Standards introduction in existing fleet;
- Vehicle Design (capacity, accessibility, modularity);
- Intelligent Garage and predictive maintenance; and
- Interface between Bus and Urban infrastructure

This deliverable concerns two of the areas, namely Vehicle Design and Interface between Bus and Urban Infrastructure. More specifically, the scope of the deliverable is the formulation of a ‘code of practice’ for new options of the design and layout of buses and the interface between bus and platform that take the new possibilities offered by hybrid and fully electric propulsion systems into account.

2.2 Approach

The primary basis for the formulation of the ‘code of practice’ is the experiences made in EBSF 2 including so called Design Charter, the results of the Gothenburg demonstration and the outcome of the simulations performed by CEIT within the San Sebastian demonstration. However, some results from the previous EBSF project have also been taken into consideration.

2.3 Organisation of deliverable

The deliverable is organised as follows:

- Chapter 1 provides the Executive Summary;
- Chapter 2 describes the EBSF 2 project, the scope, approach and organisation of the deliverable;
- In Chapter 3, results of relevance are summarised under the headings Bus, Bus Stop and Interplay between Bus and Bus Stop;
- Chapter 4 presents the principles or code or practice that can be extracted from the results presented in Chapter 3.

3 Bus System

A bus system is a transit system consisting of buses, infrastructure in terms of for example bus stops, shelters and stations, information services, schedules, routes, ticketing solutions, operational practices, etc. An overall aim of EBSF 2 is test and demonstrate different technical solutions in order to achieve cost-effective and energy efficient urban and suburban bus systems but also a bus system that attracts travellers. The overall purpose being to improve the image of the bus and increase the modal share of bus services.

A bus system that attracts travellers is a system that provides a service that is easy to understand and use, that provides efficient transport, that is reliable, and that overall results in a positive experience of a journey. A customer/user journey map is a graph that described the journey of a customer/user representing the different touchpoints that characterize his/her interaction with the service (Figure 3-1).

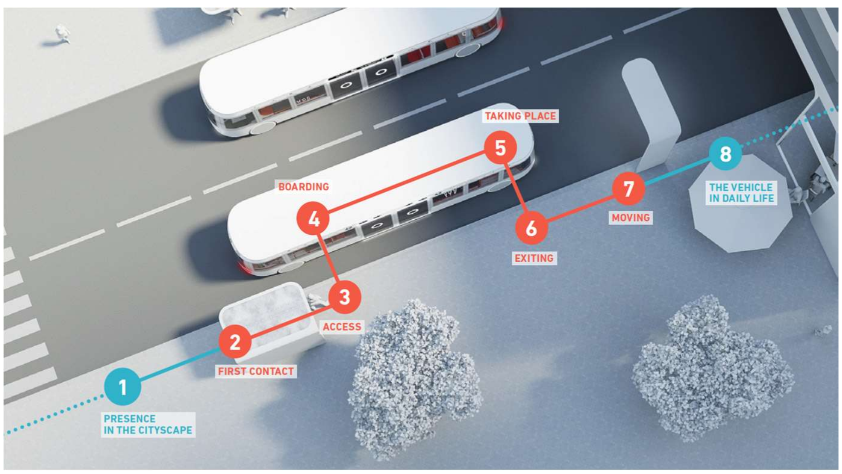


Figure 3-1. A 'user journey' illustrating the contact points between traveller, bus, and city. Source: Design Charter for Innovative Electric Buses (2018)

The touchpoints between traveller and the parts the bus system that is the scope of this deliverable is shown in Table 3.1.

Table 3-1. Touchpoints to be address in this deliverable.

Identify PT system in the cityscape	Wait	Identify bus	Board bus	Ride bus	Exit bus
Bus stop/shelter	Bus stop/shelter	Bus design, exterior	Interaction between bus and bus stop	Bus design, interior layout, seats,, lighting, etc.	Interaction between bus and bus stop

3.1 Bus design

3.1.1 The EBSF 2 Design Charter

Electric technology offers possibilities for creating new architectures, permits technical components to be placed differently compared what is feasible in buses with conventional engines, the engine can be places at the front or in the rear, doors can be centred and/or located at each end, wheels can be placed symmetrically or offset (ESBF 2 Design Charter for Innovative Electric Buses, 2018).

Within the EBSF 2 project, a design charter has been produced for innovative electric buses. Several ideas have been proposed for how to make the interior a logical, intuitive space, with easy access to all seats and spaces also for passengers with disabilities or special needs (Figure 3-2; Figure 3-3). Fundamental is to create a calm and positive atmosphere by a careful choice of shapes, materials, colour and lighting.

Figure 3-2. The bus should offer easy access to all seats. Source: Design Charter for Innovative Electric Buses (2018)

Figure 3-3. The bus could make use of the rear area of the bus, adding to the travel experience. Source: Design Charter for Innovative Electric Buses (2018)

3.1.2 The Gothenburg Demonstration

The fully electric bus in Gothenburg had a total length of approx. 10,5 m with a total capacity of maximum 85 passengers, two large double doors, low floor, and flexible/folding seats to increase accessibility, as well as new and light interior design and WiFi onboard (Figure 3-4).

The electric hybrid with a total capacity of 71 passengers had a similar colour scheme but was fitted with three doors (one in the front, one in the middle, and one in the rear part of the bus) and a more traditional interior layout (Figure 3-5).

Figure 3-4. One of the fully electric buses on line 55 in Gothenburg.

Figure 3-5. The electric hybrid buses on line 55 in Gothenburg.

Figure 3-6. The interior design of the new electric bus on line 55 in Gothenburg.

Passengers generally acknowledged the **light-green colour** of the electric bus as something new (Figure 3-4; Figure 3-6). It was described as ‘nice’, either calm or happy, as well as making the bus appear lighter. The unique colour also made it possible to spot and identify the bus from a distance. The interior was found to have a good and comfortable contrast between green and grey. Some travellers mentioned the connection to sustainability or found it well fitting in a city with many trees, while others believed the colour to be yellow.

Travellers appreciated the concept of **two large doors** in the middle of the bus (Figure 3-4). This was regarded to allow fast embarking and disembarking of a large number of travellers in a short time, and to be superior to having several smaller doors (as is a common design in standard buses). No traveller expressed any need for more doors in the front or rear part of the bus. Moreover, the risk of getting hit by a door was perceived to be smaller than on other buses, as the doors open outwards. An added benefit of having a large door in the middle rather than two or three smaller doors is that it allows the driver to have a much better view of passengers embarking and disembarking the bus.

The test bus is believed to have fewer **seats** than other buses which is the most common negative comment. The possible desire for more seats is not reflected in criticising the large open area (Figure 3-7). The **large open area** made the bus feel more open and spacious. It was highly appreciated for allowing travellers to quickly get past each other when disembarking. It was also regarded as advantageous for placing prams and wheelchairs without blocking other travellers’ paths. Some travellers want an elongated version of the bus to allow for more seats but questionnaire responses indicate that many travellers the buses on service 55 offer enough space. These results could therefore indicate that smart layout is more important than the length of the bus.

Figure 3-7. The double doors and the large floor area of the fully electric bus on line 55 in Gothenburg.

One way to create these large open areas is to have **foldable seats**. Foldable seats generally are generally considered less comfortable by the travellers possibly due to the extra effort of folding out the seat, the risk of having to give it up and stand if the bus gets crowded, or distrusting the quality of the seats. In the EBSF2 project were tested foldable seats with a high backrest and a headrest, and these seats were considered much more comfortable than regular folding seats. For people using wheelchairs the foldable seats were a very welcome addition to the buses, as that made it possible for accompanying non-wheelchair users could sit together with wheelchair users. Regarding the permanent seats, passengers comment on space. Some seats offer restricted space for their feet, other seats are placed too closed to the wall.

The **large windows** were found to make the bus appear lighter, as well as providing a good view of the exterior. Some travellers however want large windows to come with sun curtains, as they are more likely to give direct access to the sun.

The **sound level** is the most commonly mentioned factor pertaining to the electric drive, and travellers find the quiet journey a main advantage. It helps them to relax and reduces their stress level. A few travellers are however uncomfortable with talking in the silent bus as they find that others can hear them too clearly.

The bus was equipped with **WiFi and USB**-ports which were widely appreciated but not used to any considerable extent.

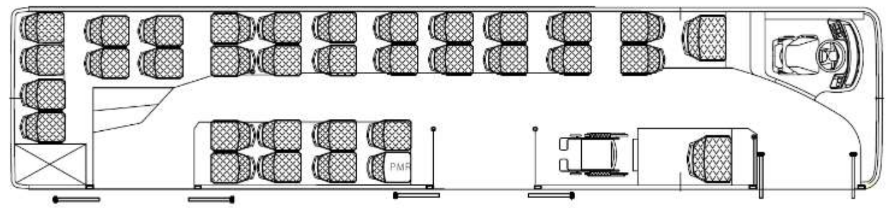
The bus is considered to express '**accessible'** already from the outside, providing immediate trust that it could be used. The large doors, the low floor, a 'kind' looking colour as well as the quiet and smooth arrival at the bus stop were factors behind this perception. Almost every traveller answering the questionnaires (99% or 100%) rated the bus easy to get on and off. The large doors for fast and easy embarking and disembarking, the large open space where travellers could pass each other, and the low floor are mentioned as the main reasons.

3.1.3 The San Sebastian Demonstration

The interior layout of the bus has an impact of accessibility, flow, and dwell times, something which has been shown in the simulations provided by CEIT. The time that a passenger needs to reach a (desired) seat or a place to stand, here called *time-to-target,* has also a major influence on travellers' perception of comfort and security. A deficient layout design will generate a very complex passenger flow onboard and the time-to-target will increase. This is particularly evident for passengers with reduced mobility (PRM), such as wheel chair users or passengers with prams or trolleys. As consequence the duration of the stop will increase, producing higher dwell times.

Therefore, reducing the time-to-target of all passengers is an essential objective when designing new layouts that optimize accessibility and dwell time. Such a new conceptual design have been evaluated and is illustrated in the following example in which two layouts are compared. Layouts A and B are the same higher capacity bus layout, reducing to number of wheel chair areas to one. To improve accessibility of wheel chair users, a critical vertical handle bar and a glass wall have been removed in layout B (Figure 3-8).

LAYOUT A



LAYOUT B

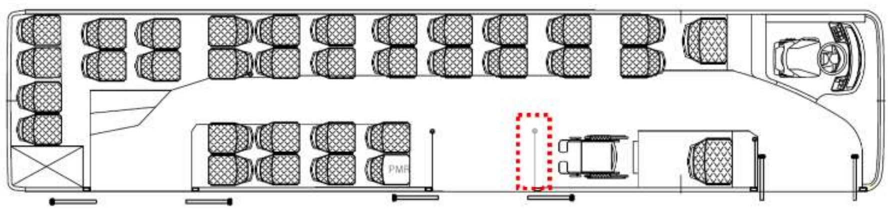


Figure 3-8: Investigated bus layouts A and B. The dotted-red box indicates the eliminated vertical handle and glass wall.

The two layout have been simulated with the Bus Passenger Simulation Tool (EBPST) including several conditions of occupancy and with a defined distribution of passenger types[1].

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[1] In the former EBSF project, Chalmers and CEIT collaborated to define eight different types of passengers, whose behaviours were identified during observational studies. To model these behaviours an agent-based simulation strategy jointly with a making-decision algorithm were developed. These algorithms were implemented within the two-dimensional simulation framework ANYLOGIC. The set of passengers includes the following behaviours:

- Soraya (24 y.o.) is the mom of Darya (6 y.o.) and Isa (2 y.o.), who travels in a baby pram. They board through the second door to secure the pram. They choose a bench seat close to the pram and Darya takes the window seat, preferably on the same side of the aisle as the pram. Any distance to the baby pram is a negative factor. Alternatively, they choose the opposite side of the aisle but without losing visual contact with the pram.
- Jacob (44 y.o., clerk) boards through the middle door. Alternatively he chooses the front or rear doors, depending on the queue size at the doors. His first choice is the window seats facing forward close to the entry doors, at the door side. Alternatively, he will choose an aisle seat. Distance to the door is a negative factor. Jacob will move to the rear part of the bus if necessary. When no seats are available, he will choose a standing spot with back support. Alternatively, he will choose any standing spot close to the entry door.
- Cecilia (41 y.o., nurse) boards through the front door. Her first choice is the window seat facing forward in the front part of the bus. Single and double seats are equally attractive. Alternatively, she will choose an aisle seat when no window seats are available. Distance is no negative factor and she would move to the middle and even the rear part of the bus to find a seat. When no seats are available, she will choose the standing spot closest to the entry door.
- Carl (21 y.o., student) boards through the third door. Alternatively, he can choose second or first door, depending on the queue size at the doors. His first choice is the window seats facing forward at the opposite side of the aisle. Second choice is the aisle seats or seats at the same side of the aisle as doors. When no seats are available, he will choose the first standing spot with hand support available.
- Harry is 83 y.o. and uses a walking frame. He boards, through the second door (to secure the walking frame). He chooses an aisle seat close to his walking frame. He has no preference for seat orientation. If the window seat is available but the aisle seat not, Harry will ask this passenger to move. Standing is never an alternative; Harry will ask other passenger to make him a seat. If the approaching bus is nearly full, Harry will wait for the next one.
- Emma (16 y.o.) and Julia (16 y.o.) always travel together. They board through the second or third door, depending on the queue size and the distance to the alternative door. A first choice is the double seats in the doors side of the aisle and facing forward. Second choice is the opposite side of the aisle. Alternatively, they will choose to seat face-to-face. Seeking for the seats, they preferably move to the rear part of the bus. Distance to the entry door is a negative factor but they will rather look for seats. If no seats are available, they will stand face-to-face or next to each other.

Figure 3-9 and Figure 3-10 present the “parking” manoeuvres that a wheel chair user has to execute to reach the target position. The manoeuvres are displayed as a sequence of simulation snapshots, recorded with the same frame rate. The visualisations clearly demonstrate that by removing the vertical handle bar and a glass wall will produce to straightforward benefits to on-board:

- The wheel chair user requires less time to reach the target (6 vs 7 frames ≈ -14%).
- The wheel chair user requires less time to reach a safe position.
- The wheel chair user executes a simpler manoeuvre, what is clearly beneficial for its comfort perception.

The aisle remains clear during the manoeuvre of the wheel chair user, producing a simpler flow of passengers on-board. Consequently, all passengers will require less time to reach their target within layout B that within layout A.

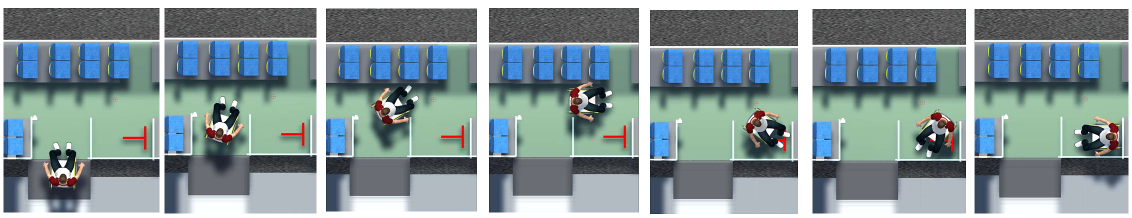

Figure 3-9: Accessibility of wheel chair user to layout A. Notice the complex manoeuvre to avoid the handle bar. (These seven images are sampled at the same frame rate than those in Figure 3.)

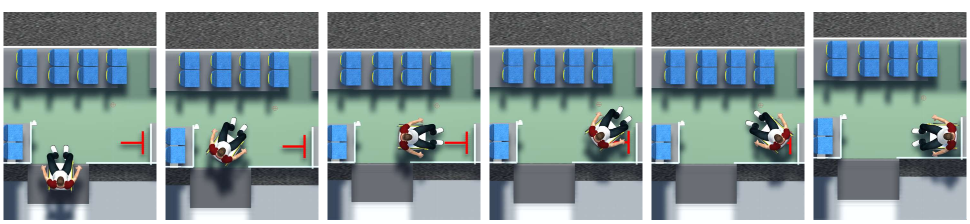

Figure 3-10: Accessibility of wheel chair user to layout B. Parking manoeuvre is much simpler and shorter than for layout A. (These six images are sampled at the same frame rate than those in Error! Reference source not found.**).**

- Hanna (27 y.o., 8 months pregnant) boards through the front door. Her first choice is the aisle seats in the front part of the bus, facing forward at the opposite side of the aisle. Window seats are never an option. She prefers double seat to a single seat. She likes to seat close to the driver (three rows at maximum). Alternatively, she will choose single seats or facing backward seats. She will never move to the rear part of the bus. Distance from the driver is a negative factor. When no seats are available, she will choose a standing spot with handrail support, preferably keeping contact with the driver.
- Roland (81 y.o.) and Elisabeth (78 y.o.) are a couple. They choose to enter the bus at the middle doors because it has a low floor. It is hard for Roland to lift his right leg due to arthritis in his knee joint. They really want to sit next to each other but this is not always possible.

How efficient a bus layout if depends also on the **passenger profile**. In principle, urban buses must target distinct profiles of passengers. For example, bus lines serving university areas may need higher capacity and faster buses to serve young people at rush hours. During off-peak hours, bus lines serving market areas might require buses with more seats and a higher level of comfort. This suggests that public transport buses should have layouts that can adapt to the expected passengers' population of the line they serve. Differences in terms of age, physical abilities and journey expectations should be taken into account to design more efficient bus layouts that optimize the flow of passengers on board, and boarding and alighting operations.

To illustrate this idea, a comparison has ben accomplished of the performance of four different layouts simulating seven different lines of DBUS network in San Sebastian. These lines differ in the distribution of passengers (Table 3-1). The investigated case studies represent complete bus journeys at non-peak hour (labour days, 12:00-13:00) of seven different DBUS lines (5, 8, 17, 19, 24, 27 and 28). Real data about occupancy (45-55%) has been provided by DBUS. This data includes age and genre distribution of passengers getting on/off the bus per bus stop.

Table 3-2: Basic profile of seven lines of DBUS network in San Sebastian. MThe most typical traveller profile is indicated.

Line #	Description	Elevation	Typical profile
5	Line connecting old town and university	Flat	Younger/Mature
8	Line connecting old town and residential zone	Hilly + Flat	Mature
17	Line connecting residential zones and hospital	Hilly + Flat	Mature/Senior
19	Line connecting old town and residential zones	Hilly + Flat	Mature/Senior
24	Line that pass through the entire city (incl. uni.)	Hilly + Flat	Younger
27	Same as line 24 but in the opposite direction	Hilly + Flat	Younger
28	Line connecting old town zones and hospital	Hilly + Flat	Mature/Senior

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Since the investigated lines differ in the actual number of bus stops, the "length" of the lines have been "resized" to eight bus stops each, with similar flow of passengers, but of different type, as shown in Table 3-3. DBUS mandatory procedure (except for pram and wheelchairs) of getting on through the front door and getting off through the other doors has been enforced.

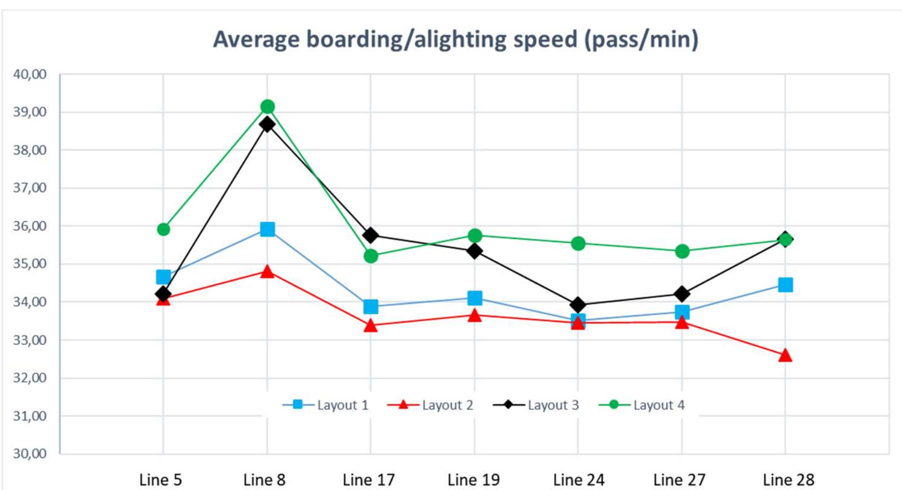
Table 3-3: Flow of passengers at each of the 8 bus stops along the normalized lines. Labels "High" and "Low" describe the amount of passengers at the bus stop and inside the bus with respect to the standard

flow of passengers of the line. For each bus line, actual rates of waiting passengers and bus occupancy are determined by the real data provided by DBUS.

Bus Stop #	Number of new passengers waiting at the bus stop	Bus occupancy rate
1, 2	High	Low
3, 4	High	High
5, 6	Low	High
7, 8	Low	Low

Figure 3-11presents the average boarding/alighting speed (passengers per min) after 10 simulations of each case (one layout-one line). Some conclusions are:

- The four layouts show a distinct performance in each bus line. No one layout has the best performance in all lines. However, a 2-door layout (layout number 2) clearly shows the worse performance in all lines.
- Bus lines 5, 24 and 27, which serve the university area and hence involve younger travellers, only benefits from layout 4. The other three layouts result in similar performance.
- Layouts 3 and 4, which provide more seats than layouts 1 and 2, show better performance in almost all bus lines, but specially in bus line 8.
- Layout 4 seems to show the best performance in all bus lines except in line 8.
- Lines involving more mature travellers (lines 8, 17, 19 and 28) do not benefit from layouts with less seats.



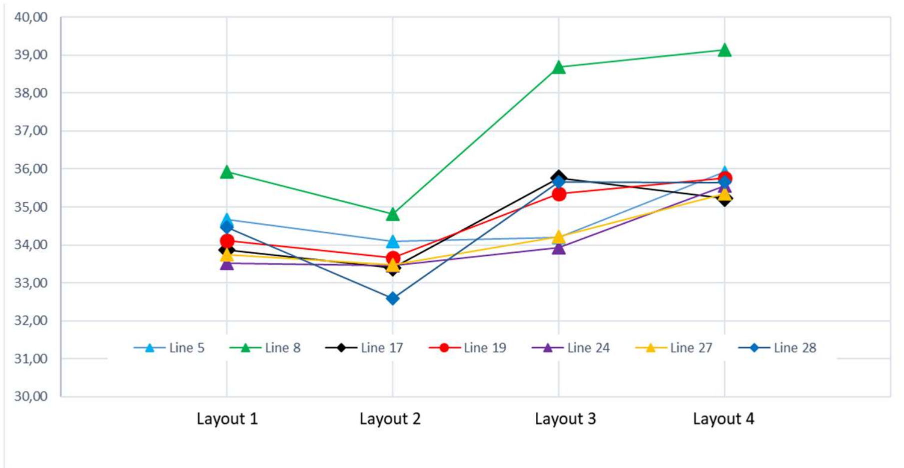


Figure 3-11. Average boarding/alighting speed (pass/min). Top: each graph corresponds to a different layout. Bottom: each graph corresponds to a different bus line.

3.2 Design of bus stop

Traditionally, bus stop have been designed to provide travellers with a landmark indicating where the bus will stop. Today bus stops have also become an important part of the image of the brand for both the operator and the public transport authority. Bus stops with shelters provide travellers with protection from bad weather but could also offer additional services to citizens, whether they are travellers or simply passers-by.

3.2.1 Gothenburg demonstration

The new bus line 55 in Gothenburg passes altogether 16 bus stops of which five were given new design.

Four of these stops include semi-enclosed shelters which are larger in size than the standard ones and which are equipped with new information features (in terms of touch monitors), free Wifi, USB-charging, and a small table (Figure 3-12(. The shelters are described to look more windproof than other bus stops without actually being the same. Some travellers recall the heated seats at one of the stops, Götaplatsen, and find this very positive during wintertime.

The shelters are found difficult to exit even with a small crowd, as large centre pillar block the way. The shelter are equipped with a screen providing real-time information but the screen hard to see within the shelter. The shelters are also equipped with touchscreens for searching travel instructions but these appear rarely used. Travellers who search for such instructions do it on their smartphone and those without a smartphone are not used to performing such searches. The screens are also found to offer poor usability. The interface returns to the first screen before travellers finish searching, and this return seems to be based on total interaction time instead of time since it was last touched.

The stop at Götaplatsen, in the centre of Gothenburg city, was the bus stop that was assessed as succeeding in the integration between the city and the bus system the best (Figure 3-13). This was probably not as much a result of the actual design of the shelter, as its location. Since it is located in an open space, in front of the city library, the whole area (including the library itself) was used as a waiting space, but at the same time one can argue that the bus stop was used as an extension of the library with people reading they recently borrowed books in the bus stop. In contrast, the other new bus stops (for project reasons) were located somewhat off the beaten path and therefore had little chance of being an integrated part of city life.

Figure 3-12. One of the new bus stop at Chalmers University campus.

Figure 3-13. The new bus stop at Götaplatsen, in the city centre of Gothenburg.

The fifth bus stop is an indoor bus stop, located at Lindholmen university campus. The building is situated in a context of university buildings, office buildings, a science park, and restaurants and forms an extension to an existing building in which is located a cafeteria and teaching facilities. Close by are also found new apartment buildings. The intention has been to create a shared space for PT and other urban activities, reducing the distance between PT and for example school or work but also change the perception of a bus stop: from “bus stop” (a place where the bus stops) to a space for activities including travel.

Travellers appreciate the indoor bus stop and the trend is constant over time. It was regarded to be a safe waiting place during dark hours, as it is light, furnished and has a size that makes it neither claustrophobic, nor desolated. The bus stop is often mentioned to be silent, as the buses are mostly idling and surrounding sounds are not let in. The two most enjoyed features are that it provides shelter from bad weather (cold, rain, wind) as well as the possibility to board and hereby secure a seat at all times. This is somewhat contradictory, as the boarding renders the indoor waiting area unnecessary. The passengers instead prefer indoor bus stops in the middle of routes where they actually may have to wait for a bus.

Figure 3-14. The outdoors of the indoor bus stop at Lindholmen in Gothenburg. Source: https://www.electricitygoteborg.se

Figure 3-15. The indoors of the indoor bus stop at Lindholmen in Gothenburg before the redesign. Source: https://www.electricitygoteborg.se

Figure 3-16. The indoors of the indoor bus stop at Lindholmen in Gothenburg before the redesign

Figure 3-17. The redesigned interior of the indoors bus stop at Lindholmen in Gothenburg

3.3 Design of interplay between bus and bus stop

The interplay between bus and bus stop is essential when passengers are boarding as well as when existing the bus. The interplay is important for the flow of passengers entering and leaving the bus and therefore also the dwell-times. For passengers with walking impairments, passengers using walking frames or wheel-chairs a ‘misfit’ between the entrance door of the bus and the platform can be the difference between being able to use and not being able to use PT.

3.3.1 The Design Charter

The design charter emphasises the importance of barier free accessisbiity, that boarding and disembaring should be achieved without constraints, and that the flow from/to bus/stop and its platform should be efficient in order to reduce, e.g. dwell times. However, what is also emphasized is the feeling communicated through the design – passengers should feel welcome and welcomed!

Figure 3-18. The flow to/from bus and bus stop/shelter is important to consider in the design of the bus system. Source: Design Charter for Innovative Electric Buses (2018)

3.3.2 Gothenburg Demonstration

The two very wide doors of the electric concept bus was beneficiary to passenger flow. With such wide doors and ample room in the bus behind them, passenger were able to easily get on and off. In particular it was considered positive that people was able to get of the bus even after other passengers had started entering the bus. The bus stops were, with the exception of the indoors bus stop, designed to benefit from the big central doors. Here it was instead observed that the big table and installation of several monitors at or below eye-height made it difficult for passengers to pass.

The concept bus tested in Gothenburg was found to have superior **accessibility** compared to previous, standard buses. The wide doors, the flat open and very low floor, combined with the rather high platforms made it possible for walking frame users as well as most wheelchair users to enter the bus themselves, without having to fold out any ramp. This increases the independence of these passengers, and at the same time shortens dwell times.

When analysing actual dwell times at line 55 it could be observed that while getting off the bus was faster with the electric concept buses, the total dwell time was higher than for the hybrids (although still shorter than for the other bus line used for comparison). We attribute this to the bus drivers having superior visibility of the passengers in these buses and that they actually waited for all passengers to be seated before leaving the bus stop, which is not the case with the standard buses.

3.3.3 San Sebastian Demonstration

With an intention to design a bus stop/shelter not only as an area for waiting for the bus, but also for example for socialising or (as was the case with the EBSF bus stop), a more complex flow of travellers and passers-by can be expected.

To envisage some of the key aspects, the bus stop designed within the former EBSF project has been modelled and simulated in two modes of use (Figure 3-19Figure 3-19) (see also EBSF D2.1.4 Performance Evaluation).

Figure 3-19:The 'EBSF bus stop' ar Gare de Lyon-Diderot, Paris.

In the first simulation, passengers are spread across the entire surface of the bus shelter. In the second simulation, passengers wait only in the area facing the bus. For each of the scenarios 20 passengers of different types (5*Jacob, 5*Carl, 5*Hanna and 5*Cecilia) are simulated. The key factor affecting dwell time is here the *walking-to-door* (W-t-D) distance.

Figure 3-20: Passengers' trails. Dots indicate waiting position of individual passengers and colours indicate types of passenger. In this case passengers are waiting on the entire surface of the bus stop.

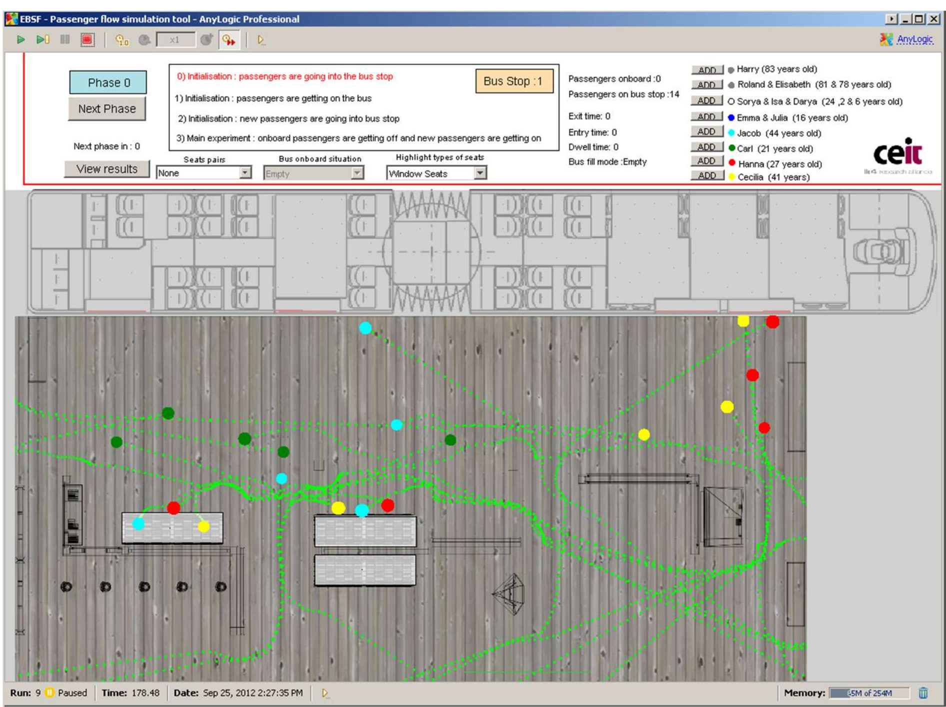


Figure 3-21: Passengers' trails. Dots indicate waiting position of individual passengers and colours

In general, the dwell times obtained for the first scenario were longer than for the second one (Figure 3-22; Figure 3-23). The simulation results clearly show that the wall that, in this case, splits the bus stop in two has a very negative effect on dwell time.

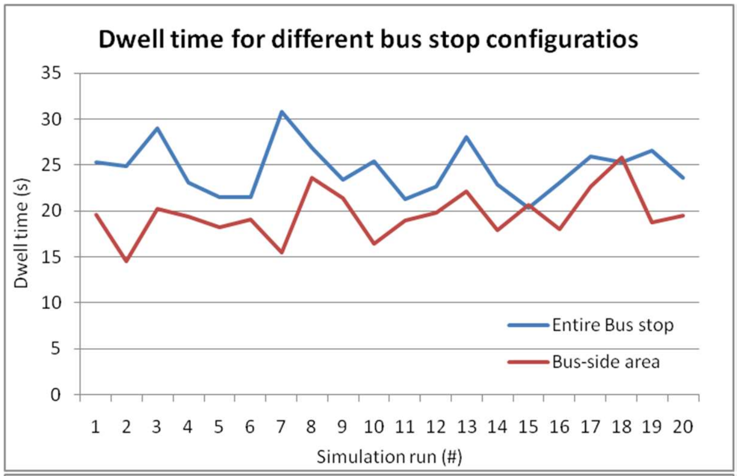


Figure 3-22:Dwell times for different bus stop uses (20 simulation runs).

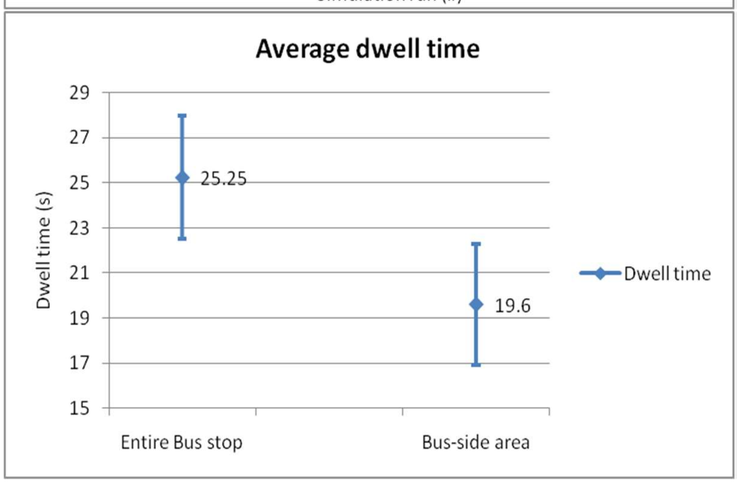


Figure 3-23:Average dwell times and their standard deviation (20 simulation runs).

Earlier simulations have shown that efficient boarding and alighting depend also on operation procedures (EBSF D12.4.). Front-door-only boarding is likely to increase dwell time, i.e. the more travellers that are to pass through one door, the slower boarding is. Changes in the design of either the bus layout and/or the bus stop layout to cope with an increase of the number of passenger can become useless if these are only allowed to get on through, for example the front door. Dwell time can sum up to a third of bus travel time[2].

[2] On the 11 busiest Minneapolis Metro Transit bus corridors, 32% of travel time was spent stopped waiting for customers to board. MetroTransit, "Arterial Transitway Corridors Study Summary," April 2012. Accessed via: http://www.metrotransit.org/Data/Sites/1/media/pdfs/atcs/atcs_ summary.pdf.

As an example, the software was used to analyse Line 28 of DBUS in San Sebastian, which has 12 bus stops in total, of which three are small, 6 medium sized and 2 large (see also D12.4.). Three simulation case studies have been performed with the following data:

- Bus layouts: Two standard 12-meter buses, with two and three doors, have been modelled with the Layout Editor. These are Layout A and Layout B in Figure 3-24. **Error! Reference source not found.**
- Two boarding strategies have been considered: getting on only through the front door versus getting on through all doors.

LAYOUT A:
3-door layout

LAYOUT B:
2-door layout, rear door is not available for boarding

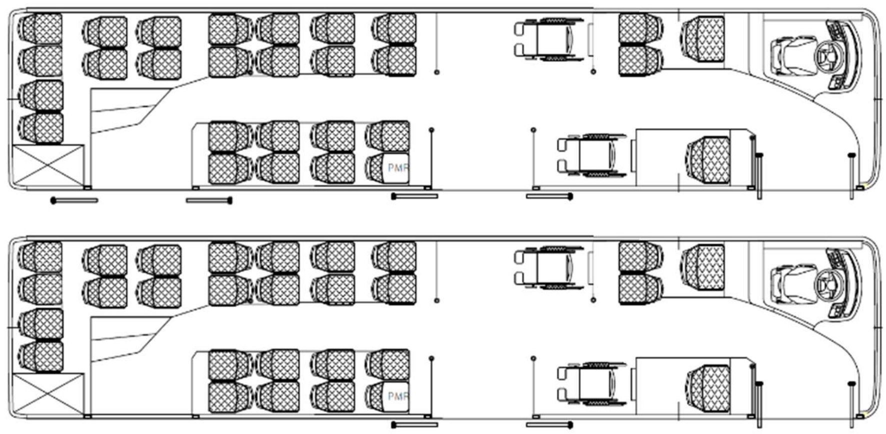


Figure 3-24: The investigated bus layouts A and B. The layout corresponds to the IRIZAR's I2E electric bus.

The population of passengers corresponds to an off-peak situation. The distribution of passenger profiles was determined by direct observation. Seven types of passengers were identified, including one wheel-chair user (Table 3-4).

Table 3-4. Flow of passengers at each bus stop of the line 28 of DBUS (off peak hour, labour day).

Stop	0		1		2		3		4		5		6		7		8		9		10		11	
Behavior	Get on	Get off	Get on	Get off	Get on	Get off	Get on	Get off	Get on	Get off	Get on	Get off	Get on	Get off	Get on	Get off	Get on	Get off	Get on	Get off	Get on	Get off	Get on	Get off
Carl (21 y.o.)	8		5		1	2			1	2	1	3	1	4	2	5	1	3	1	1		1		
Cecilia (41 y.o.)	2				1						1	1	1	1	3	3		3			1			1
Hanna (27 y.o.)																	1			1				
Harry (83 y.o.)	1		1		1			1						2										
Jacob (44 y.o.)	2		2				1	2				2	3	1		2				1				
Roland (81) & Elisabeth (78)	2		2							2						2								
Wheelchair user	1																	1						

Figure 3-25 shows the average dwell time per bus stop and Figure 3-26 shows the average exit time estimated for both the 3-door and 2-door buses, with passengers getting on only through the front door. The simulations were repeated 100 times. The numbers suggest that dwell time is mainly affected by the obligation of getting on the bus through the front door. The existence of the third door is not beneficial at all for the boarding operation. This fact is confirmed by the analysis of the exit time. The third door is clearly beneficial for the exit time, but this reduction of time is not enough to counteract the obligation of getting on through the front door. If this operator's policy is removed, the average dwell time noticeably diminishes in the busiest bus stops, as shown in Figure 3-27.

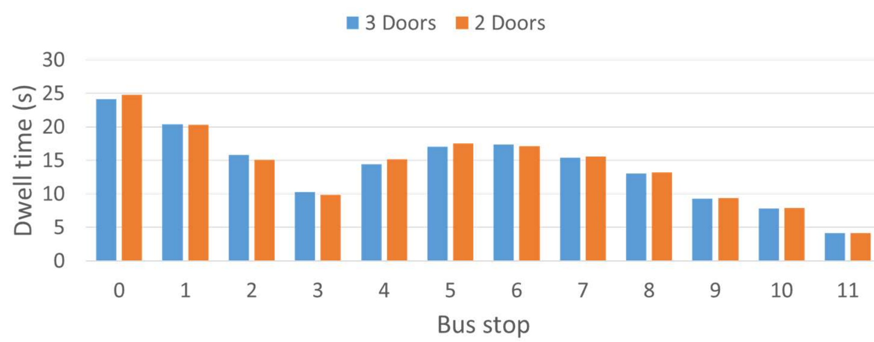


Figure 3-25:Average dwell time per bus stop (3-door vs. 2 door, passengers get on only through the front door).

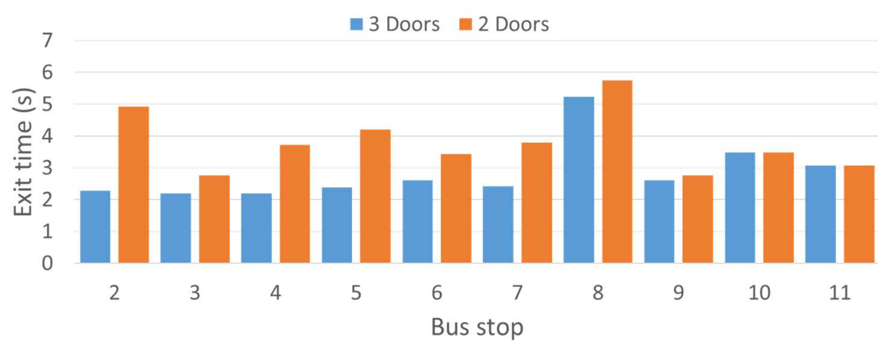


Figure 3-26: Average exit time per bus stop (3-door vs. 2-door buses, passengers get on only through the front door).

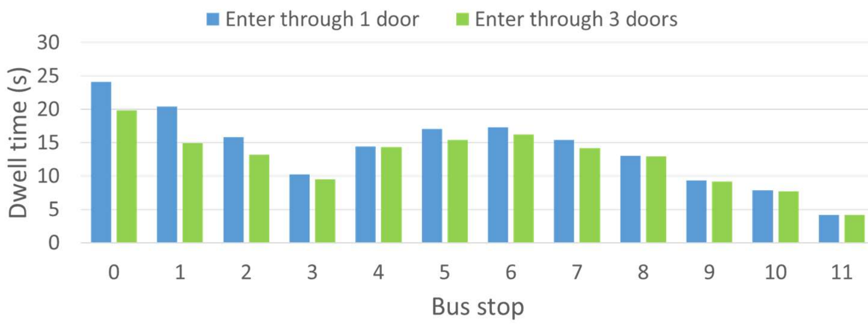


Figure 3-27: Average dwell time for the 3-door bus with passengers getting on only through the front door (blue) and through all of them (green).

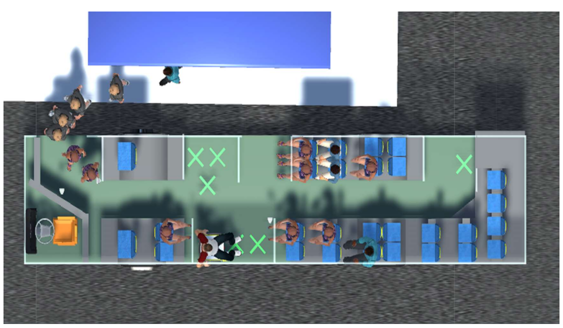
Figure 3-28 and Figure 3-29, which show two similar but different simulations, provide visual cues to understand the situation in more detail. When passengers can board only through the front door, they are forced to form a queue at the bus stop. Depending on the length of this queue, and the time required for the ticket purchase/validation process, the bus will have to remain still for a shorter or longer time.

Figure 3-28: Passengers boarding a 12-meter 2-door bus (layout B). Front-door-boarding. Bottom: all-door boarding

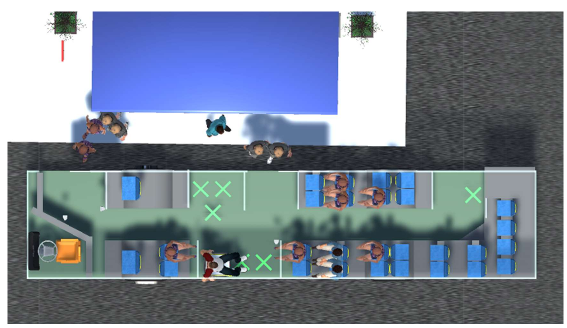
Figure 3-29: Passengers boarding a 12-meter 2-door bus (layout B). All-door boarding

Allowing all-door boarding, the queue would split in two shorter ones, reducing the time needed for boarding. However, the long queue that exits in front-door-only boarding has a clear benefit regarding the on-board flow as passengers approach their selected targets and obtain them on a "first-come, first-served" basis. The only perturbation to this would be related to the interaction with passenger with mobility issues, such as wheel chair users, and traveller with prams or trolleys.

Front-door boarding



All-door boarding



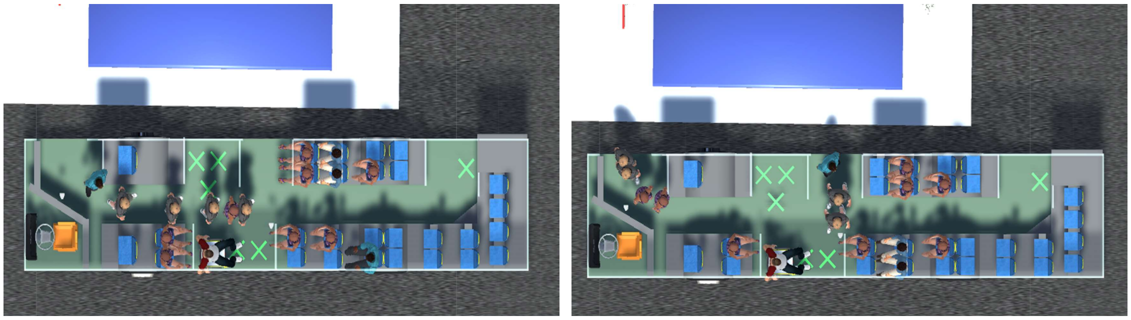


Figure 3-30: Passengers boarding a 12-meter 2-door bus (layout A). Left: front-door-boarding. Right: all-door boarding.

Boarding through all doors creates a more complex flow, which will be easy to manage by passengers it there are not too many competing for the same target, or there are plenty of targets for all of them (Figure 3-31).

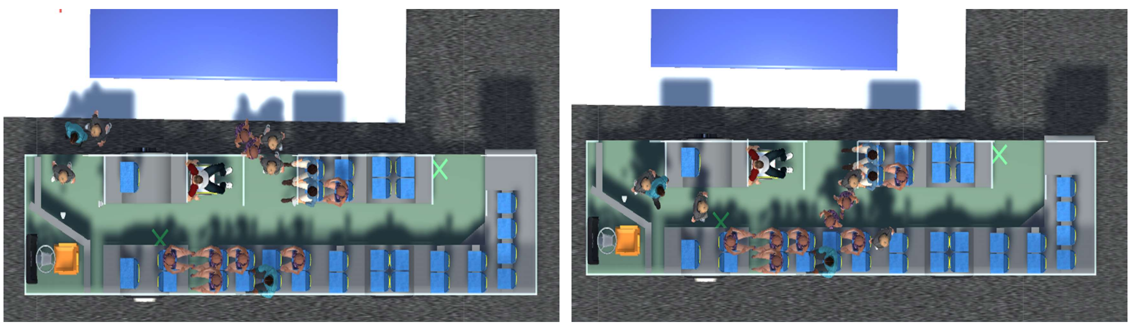


Figure 3-31: Passengers boarding a 12-meter 2-door bus (layout #4). This layout provides can satisfy a high demand of seats in the middle area of the bus.

Therefore, adapting the design of the bus layout to a specific population could reduce dwell time and improve the efficiency of the line, but possibly will not be enough to counteract the negative effect of front-door-only boarding. Conversely, changing the operator's procedures allowing all-door boarding has a positive effect on reducing dwell time.

Another important factor influencing dwell time is the time spent by the passengers walking between their waiting points at the bus stop and the selected bus door. This time is directly related to the design of the bus stop.

Figure 3-32, Figure 3-33, and Figure 3-34 show the simulation of some passengers boarding a 12-meter 3-door bus, from three bus stops of distinct sizes. All doors can be used for boarding. The bus stop corresponds to the bus stop designed in the former EBSF project (Figure 3-19).

The benefits in terms of dwell time if combining a 3-door bus with an all-door boarding strategy will materialise only if the boarding time is reduced. In case of bad weather conditions (strong wind, snow, rain, hail, etc.) passengers probably will wait inside the bus stop. If the bus stop is small (as in Figure 3-32), passengers will have to walk larger distances to get on the bus, than if the bus stop is large (as in Figure 3-33(:

- Shelters and small bus stops are less likely to benefit from the potential reduction of dwell time associated with a 3-door bus implementing an all-door boarding strategy.
- Conversely, bigger bus stops are much likely to take advantage of 3-door buses with the all-door boarding strategy.

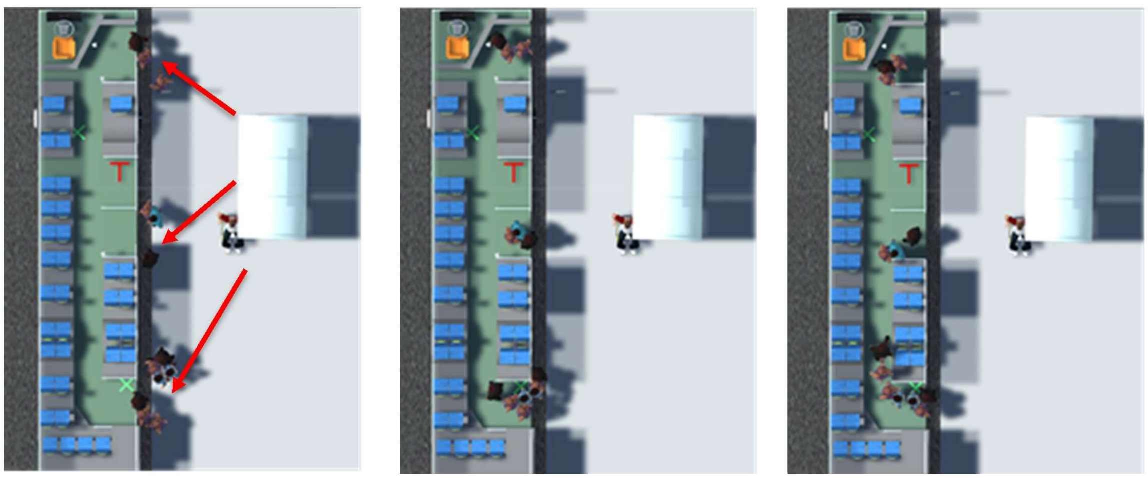


Figure 3-32: All-door boarding in a 12-meter 3-door bus (layout #4) from a small bus stop.

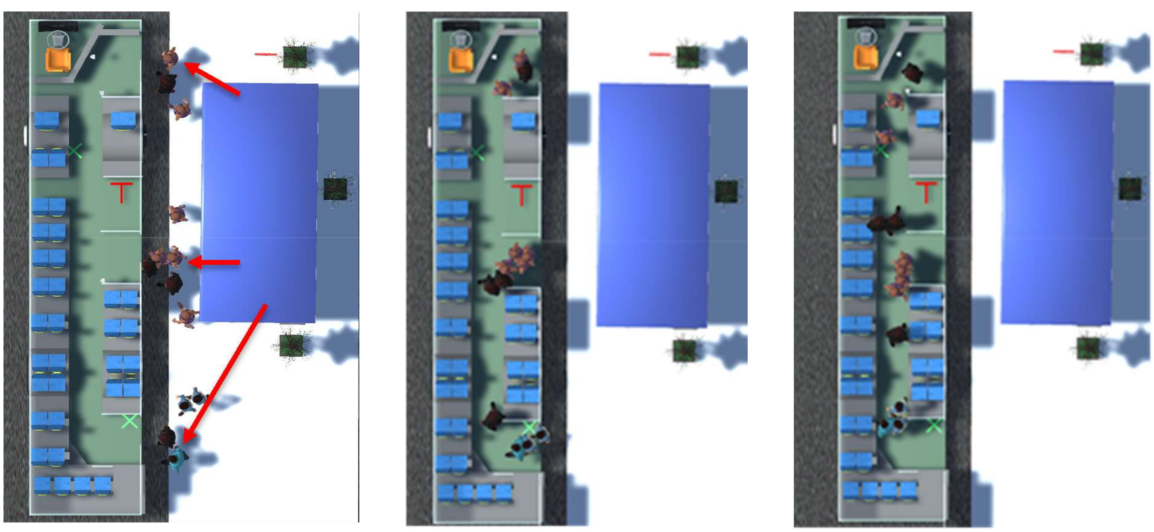


Figure 3-33: All-door boarding in a 12-meter 3-door bus (layout #4) from a medium size bus stop.

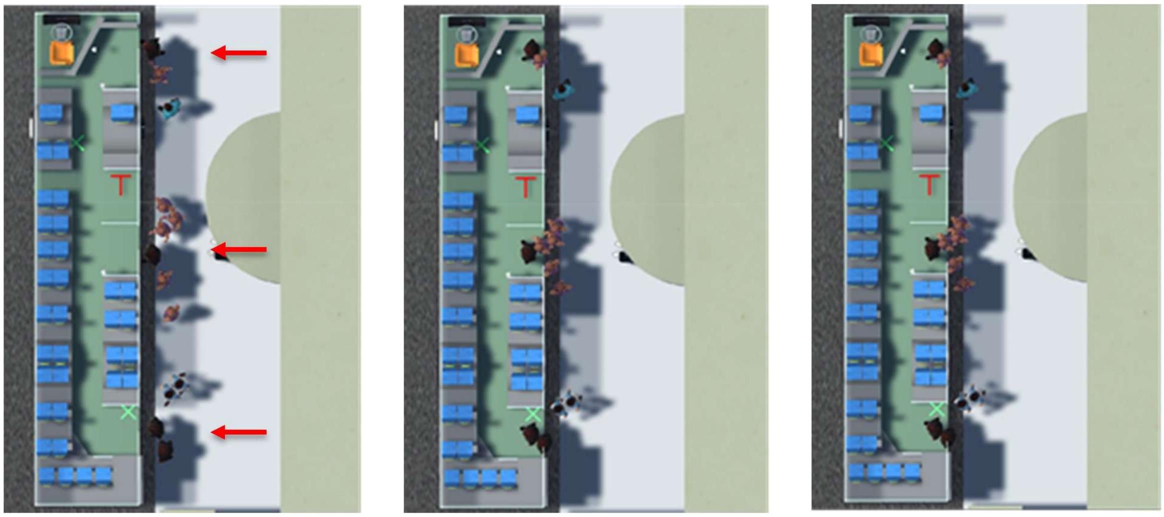


Figure 3-34: All-door boarding in a 12-meter 3-door bus (layout #4) from a big bus stop.

One methodology to reduce the *walking-to-door* (W-t-D) time is to indicate where exactly the bus will stop. This can be accomplished by, for example, painting loading areas on the ground indicating exactly where each door will (should) be located once the bus stops.

Two simulation experiments were conducted to analyse how walking time affects dwell time at a bus stop (see also EBSF D2.1.4). In the first experiment, all passengers are aware of where exactly the boarding door will be located and they choose their waiting point closer to the loading areas. In the second experiment, no indications are available and passengers waiting points are distributed over the entire bus stop. In this case, walking distance is correlated with the bus stop dimensions. The simulated bus stop is a larger bus stop, with approx. an 80 square meter surface, which is adequate to serve an 18-meter 3-door bus implementing the all-door-boarding strategy. Figure 3-35 shows the path followed by passengers during the respective cases.

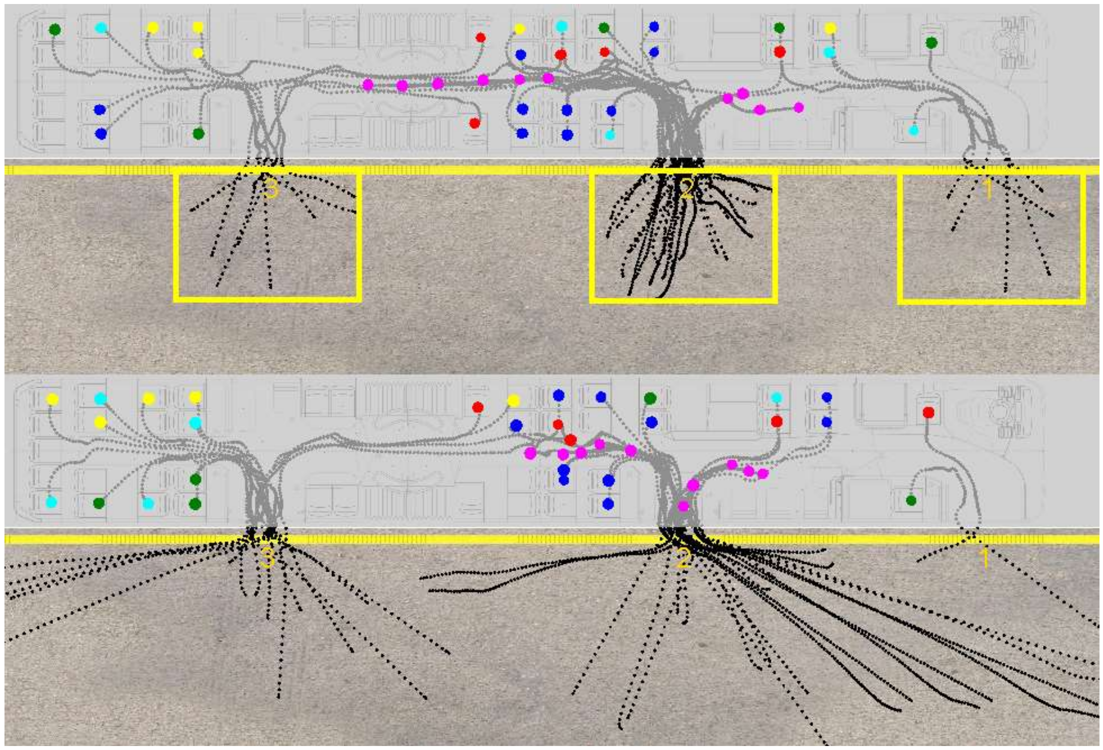


Figure 3-35: Paths followed by 40 passengers while boarding from designated areas (upper image) and entire bus stop (lower image).

Both boarding strategies have been simulated with 40 and 80 passengers respectively. Boarding from the loading areas results in shorter walking times and thus overall dwell times. For the experiment involving 40 passengers the average dwell time was shorter by 9 seconds. In case of 80 passengers, the average dwell time for both situations are similar but the standard deviation is much higher if passengers wait over the entire bus stop before the bus arrives.

When 40 passengers are boarding from the indicated areas, the general dwell time is shorter. However, with a higher number of passengers, the influence on walking time on dwell time appears to be minor. The reason for that is the fact that a higher number of passengers boarding require longer queues at entry doors and the delay provoked by the longer walking times when boarding from entire bus stop could become insignificant. Moreover, the simulation results show higher variability of behaviours, which is reflected by wider range of standard deviation in Figure 3-36.

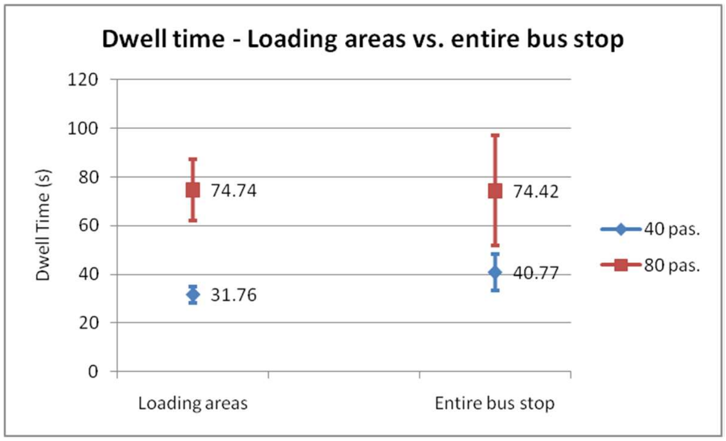


Figure 3-36. Average dwell time and its standard deviation (100 simulation runs) for boarding from loading areas (left) and from entire bus stop (right).

The walking time is gaining in importance when some crowding emerge at the bus stop platform (i.e. passengers waiting for the next bus arrival). In addition, it often happens that some passengers arrive late to the bus stop provoking the raise of the dwell time.

4 Summary and Implications

- Electric technology offers possibilities for creating new **bus designs**. As emphasized in the Design Charter (EBSF 2 Design Charter for Innovative Electric Buses, 2018), it allows technical components to be placed differently compared what is feasible in buses with conventional engines. The engine can be placed at the front or in the rear, doors can be centred or located at either end, and wheels can be placed symmetrically or offset. The Design Charter illustrates several possibilities for a new exterior design as well as new interior layouts which can benefit passengers, manufactures, operators, as well as cities.

- The bus must be designed so that it is easily identified – the Design Chater chose the term 'Regonisable' – as a bus, as a bus operating a line with a specific destination, but also as an electric (or perhaps hybrid) bus and hence a new type of bus with associated meanings such as sustainability.

- The bus must be designed for safe and easy boarding and existing as well as for a logic flow through the bus. In general, big central doors and the open flat floor space made possible by the electric drivetrain with wheels "in the corners" appear to be a step forward. However, the simulations provided by CEIT shows how details in the design of the interior layout can have a large impact on flow, and consequently on the efficiency but also the safety of the bus system.

- Moreover, electric or not, installation of ticket validators, stop buttons and information displays need to be carefully worked out. Minor details as they might seem, they have a large impact on the overall perception of the bus and the bus system.

- Electric buses offers the possibilities to create a completely new type of **bus stop**, in connection to or (even though not demonstrated in the project) even as an integrated part of, for example office buildings or shopping malls. The demonstration in Gothenburg has shown that an indoor bus stop is feasible. However, in order to reap the true benefits of indoor bus stops it is essential to consider where along the line that they are placed and if and how they are integrated with the cityscape.

- The design of the bus stop layout must take into account the needs and requirements of the different services provided without putting at risk the efficiency of the bus stop. The simulations provided by CEIT shows how different elements, such as partitioning walls and the like, can results in longer and less efficient boarding.

- The results show that a systems perspective is necessary in order to design an efficient and attractive bus system. A bus system is a system consisting of buses and infrastructure in terms of for example bus stops, shelters and stations but also of information services, schedules, routes, ticketing solutions, operational practices, etc.

- The customer journey map, and the touchpoints between traveller, bus, bus stop etc., during a journey with public transport, provides a good basis for designing a bus system.

Identify PT system in the cityscape	Wait	Identify bus	Board bus	Ride bus	Exit bus
Bus stop/shelter	Bus stop/shelter	Bus design, exterior	Interaction between bus and bus stop	Bus design, interior layout, seats,, lighting, etc.	Interaction between bus and bus stop

- The type of simulations provided by CEIT is an important design tool, not only for design of the bus but also for the design of the bus, the design of the bus stop, and the interplay between bus and bus stop including boarding principles (e.g. front door only versus all door boarding).

5 Partner Contribution

The following partners have contributed to completion of the deliverable as specified below.

Institution/Company	Sections	Description of the partner contribution
Chalmers University of Technology	All	Chalmers created the template, wrote Chapters 1,2 part of Chapter 3 by contributing with input on the Gothenburg demonstration results, and Chapter 4.
CEIT	Chapter 3	CEIT contributed wo Chapter 3 with input from the San Sebastian demonstration, in this case the results of the different simulations.
UITP	All	UITP performed a quality check of the content of the deliverable.

End of the Document