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Session 1

Schienenpersonenverkehr

Passenger Rail Transport

Accessibility to passenger trains: review and tests of innovative solutions

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Summary

The accessibility requirement at the level of the train-platform system is essential for all railway passengers. However, it becomes of crucial importance when it refers to Persons with Reduced Mobility (PRM) or, in any case, people with temporary or permanent disabilities to whom it is necessary to guarantee safe and, at the same time, comfortable train access. Within the framework of the EU-funded project CARBODIN, MASATS, as a partner of this project, has conceived and built a prototype used for simulating and assessing the train accessibility for PRM. In this context, the paper describes the theoretical concepts and the experimental approach for testing a mock-up embedding a novel technical device to fill the existing horizontal and vertical gaps between trains and station platforms. Such a device is formulated to reduce, or at best, remove the physical barriers at the interface between the train and the station platform, thus providing a solution for autonomous boarding of PRM.

Keywords: accessibility, train-station system, boarding equipment, interoperability, PRM

1 Introduction

Accessibility to infrastructure and service is a relevant feature in all mobility systems regardless of the transport mode. It becomes a crucial issue in rail-based systems, intended as discontinuous because accessible in specific network nodes, i.e., stations. The station represents the first interface between the rail and the landside. To be entirely usable, it must allow passengers to cover independently and safely the route linking the entrance with its main functional areas, e.g., ticket office, waiting room, services toilets, and tracks. A second inner level, at the running plane, is the train-station platform system. Both former and latter interfaces must be fully accessible to provide all rail users with a safe and comfortable travel experience. Within the framework of the EU-funded project CARBODIN [1] belonging to the Shift2Rail Research Joint Undertaking, MASATS, as a partner of the above project, has conceived and built a prototype used for simulating and assessing the train accessibility for Persons with Reduced Mobility[1] (PRM). Following the operational and technological improvements reached in recent years, such a prototype embeds a novel technical device to fill the existing horizontal and vertical gaps between trains and station platforms. According to that, the paper aims to describe the theoretical concepts and the experimental approach for testing such a solution formulated to reduce, or at best, remove the physical barriers at the interface between the train and the station platform. This means creating suitable conditions allowing a *self-sufficient* use of the trains, principally by PRM passengers and promising safe and comfortable train access without restrictions or discrimination for all users.

2 The train access system: a crucial issue

Train access systems, namely doors, steps and ramps, are the crucial interfaces between station platforms and trains. They primarily enable all passengers to board and alight the train. Besides, they perform further relevant functions; more properly, they ensure passenger safety, support demands of disabled people and persons with reduced mobility and optimize dwell time at stations. They also contribute to increase comfort for train travelers as a whole.

According to a comprehensive literature review, failures of train doors are the most relevant single cause of delay and disruption of rail transit service [2], [3], [4] and [5]. Despite the extensive implementation of the electric doors and related features (e.g., sensitive edge, push-buttons, slim design, etc.), train accessibility systems are still affected by a low level of reliability and safety, thus being one of the main components causing disruptions and accidents, sometimes with severe consequences for involved passengers. Besides, such an issue becomes more critical for regional, urban rail and mass

[1] PMR TSI defines (cf. §2.2) a person with disabilities and a person with reduced mobility *"[…] any person who has a permanent or temporary physical, mental, intellectual or sensory impairment which, in interaction with various barriers, may hinder their full and effective use of transport on an equal basis with other passengers or whose mobility when using transport is reduced due to age".*

rapid transit systems characterized by many stops along the line with frequent alighting and boarding passengers (with or without baggage).

Besides, in case travelers are PRM currently, there is no solution for their autonomous boarding, thus implying that dedicated procedures are required to enable a coherent operation between Infrastructure Managers (IM) and Railway Undertakings (RU) managing assistance services for disabled passengers boarding and alighting from trains. Such services, activated upon reservation in advance, are always necessary for wheelchair passengers. Since the time required for booking is quite large, this prevents the disabled passenger from making short-term travel decisions.

All the above, both from a functional and operating point of view, stresses how the room for further improvements in such a field is still high (Table 1, in bold objectives and contributions of the paper).

Table 1 - Key objectives and technology contribution improving service quality

Key Area	**Key objectives**	**Technology contributions**
Improved services and customer quality	**Increase train accessibility for PRMs** **Passengers safety and comfort improvement and enhanced PRMs traveling experience** Increased capacity due to improved passenger flow by introducing innovative passenger access systems	**Innovative vehicle access systems (i.e., a vertical and horizontal gap filler) allowing** ▪ **independent and faster boarding for all passengers** ▪ **an unassisted and easy PRM access** New architectures, new materials and technologies for an optimized access solution (thermal, acoustic performances, and weight) Contactless passenger detection by using new sensor technologies

3 Methodology

The methodological approach includes two serial activities. The former deals with the research step covering the requirements to fulfill in order to arrange safe and comfortable access to train; the latter provides a specific focus on the demonstration activity by defining the test procedure involving a sample of PRM as descriptive and heterogeneous as possible. More properly, to ensure that the theoretical concept can be fully developed and then translated into a real demonstrator, the first research activity includes the review of the design specifications, both in terms of functional and technical requirements, of the filling gaps boarding equipment. The second activity is a test with a physical demonstrator, a mock-up consisting of a metal frame capable of emulating the side panel of a typical train wagon. Such a prototype, to be intended as a stationary apparatus made available at the MASATS manufacturer premises sited in Barcelona/Manresa (Spain) - accommodates two types of devices, as follows: (1) a gap filler bridge/ramp device, (2) a complete door system composed of a mechanism and two-door leaves (sliding/plug movement).

The next sections include a presentation and discussion of the theoretical framework and the experimental approach developed for planning the testing activity.

The conceptual development, the building of the boarding equipment, and the testing procedure on train accessibility for a representative panel of PRM have been completed. However, scheduling demonstrative activity about the boarding aid tests has been delayed because of the mobility restrictions due to the Covid-19 pandemic. That's why at the time of writing is still not possible to quantify the advantages of testing such a new solution. Nevertheless, it is realistic to suppose that the main outcomes will likely deal with a lowering of time for autonomous PRM entrance to the train and an increase of accessing passenger comfort along with a reduction of waiting time of the train in the station compared to the situation where the boarding equipment is manually handled.

3.1 The theoretical framework

The PRM Technical Specifications for Interoperability[2] (TSI), commonly recognized as the regulatory and technological focal point for improving the PRM accessibility to rail systems [6], cover all the essential requirements (§2.3 (3) PRM TSI) referred to passengers' safety. Among them, platform and onboard ramps need a manual, semi-automatic or automatic device that is *positioned between the vehicle door threshold and the platform* (4.2.2.12.2 PRM TSI), representing the Interoperability Constituents[3] (IC),

[2] PMR TSI defines (cf. §2.2) a person with disabilities and a person with reduced mobility *"[…] any person who has a permanent or temporary physical, mental, intellectual or sensory impairment which, in interaction with various barriers, may hinder their full and effective use of transport on an equal basis with other passengers or whose mobility when using transport is reduced due to age"*.

[3] Directive 2016/797, repealing the Directive 2008/57/EC, which in art.(2) states: "(7) *interoperability constituents' means any elementary component, group of components, subassembly or complete assembly of equipment incorporated or intended to be*

both for Infrastructure and Rolling Stock sub-systems [7]. Therefore, as far as the train entrance system is concerned, by taking into account TSI mandatory rules, the focus is on the following key features and sub-systems:

1. Platform height;
2. Distance between the platform and the doorsill;
3. Residual gap between the gap filler and the platform;
4. Slopes;
5. Platform position and measurement systems.

To reduce both horizontal and vertical gaps between the door threshold and the platform, according to the EN and TSI standards, the boarding support must be adaptive to an extensive range of platforms, specifically European standard platforms (550 mm and 760 mm). In doing so, this device allows covering a gap of more than 200 mm and a stroke between 150 mm and 550 mm (Figure 1).

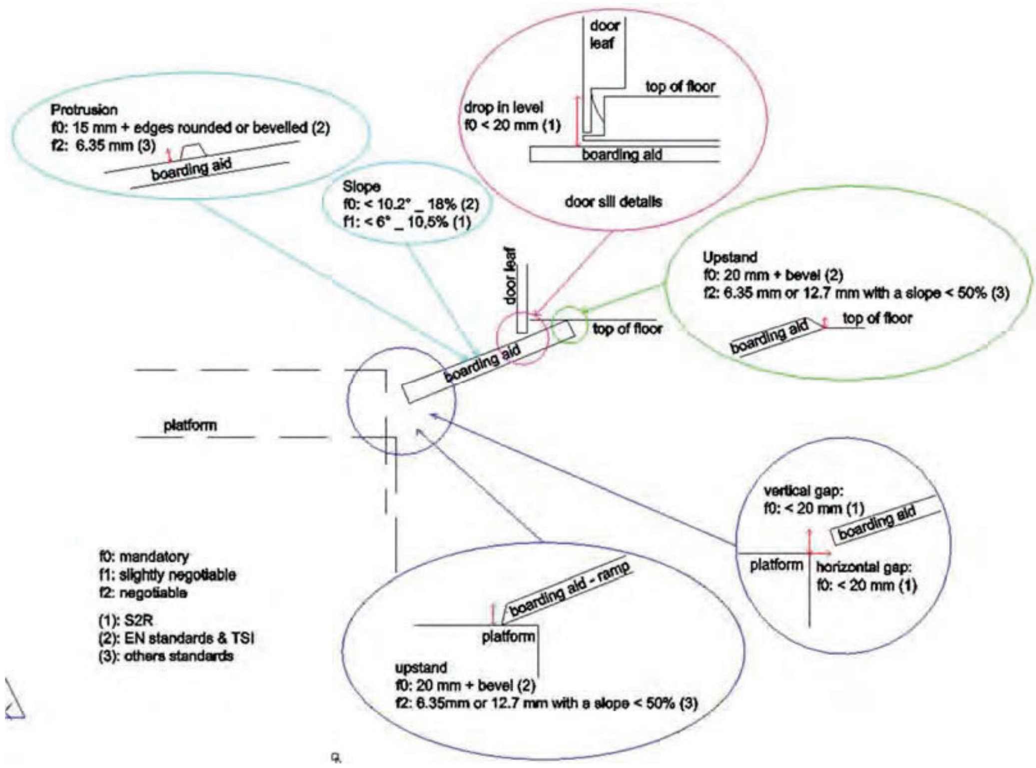

Figure 1 – EN & TSI standards, regulations constraints [8]

incorporated into a subsystem, upon which the interoperability of the rail system depends directly or indirectly, including both tangible objects and intangible objects".

Furthermore, with regard to the platform height, the train must allow easy and safe access for both the 760 mm and 550 mm platform typology, as regulated by the TSI. By referring to a sample composed of more than 80% of the 550 mm platforms measured in France, the height tolerance values range respectively between [-30 mm] and [+ 55mm] for both the nominal platform height.

Moreover, depending on the station type and its curvature radius, the trains' operating speed, as well as on the type and length of the train stopping at the station (because of the vicinity between door position and bogie), the cant varies greatly. This gives rise to a broad set of configurations shaping an extensive distance range between the platform and the doorsill (Figure 2).

Figure 2 – Platform and train interface [9]

According to different railway services, the values depending on the door position and the platform design are within the following ranges:

- Metro: min = 80-150 mm; max = 200 mm;
- Regional and High-Speed: min = 80-120 mm; max= 500 mm.

After the adjustment of the step height, the target of 20 mm is set up for the residual vertical gaps between the platform and the end of the sliding step of the vehicle. This is fully compliant with the TSI PRM that set level access of 50 mm. As far as the horizontal gap is concerned, the target is 20 mm too; in such a case, the level of access as defined by the TSI PRM is 75 mm.

Moreover, to allow easy and safe access, the slopes in the train access area should be limited to a 6% target value; this implies a related upstand (protrusion) of 20 mm at both ends; possibly reduced to 10 mm if the ramp splits twofold or stow. Anyway, at the

European level, according to the TSI PRM, the slope cannot exceed 18%, which is an angle of 10.2°[4].

According to the main features related to the concerned boarding equipment, Table 2 summarizes the functional requirements associated with the single phases of the device operations.

Table 2 – Device operation: functional requirements setting

Functional steps	**Requirements**	**Recommendations**
Deployment and retraction	Deployment and retraction of the device shall be automatic	Ramp or access devices should not invade the platform in order to avoid passenger injuries (contact or impact on passenger present on the platform near the edge)
Preliminary adjustment	Perform preliminary adjustment of the height before the train is at standstill to reduce the dwell time Platform heights and distance should be known before the train is at a standstill	Longitudinal slopes inside the train rather than lateral slopes should be implemented Accumulation of the lateral slope of the floor with the slope of the train (up to 8%) must be avoided to avoid risk of having unacceptable slope values
Behaviour of the entrance system	Entrance system shall always act as a *level access*.	Gap filler is always adjusted to the platform height and distance
Adjustment during boarding, alighting and stop in station	Due to enter/egress of passengers in the train, the wagons weight may change and then the height of the floor also. The floor's height must remain constant because the train secondary suspension will nearly always compensate for the change of vehicle weight.	No adjustment during boarding and alighting for the adaptive gap filler

[4] slope as angle for an elevation of 18 m over a distance of 100 m is calculated as follows: *tan(α)= [(18m)/(100m)] => α = Arctg 0.18 => 10,2 °*

3.2 Functional features for the simulation process: mock-up designing

As mentioned above, the stationary mock-up accommodates the following two types of devices: (1) a gap bridge/ramp device, (2) a complete door system made up of a door mechanism and two-door leaves (Figure 3). The maximum vertical gap compensated by the device is 140 mm, while the maximum horizontal gap is 300 mm. The ramp/gap bridge has a minimum effective width of 1300 mm and its opening will always be from a higher train position to the platform. To provide an overview of geometric characteristics, the general dimensions of the ramp are in Table 3.

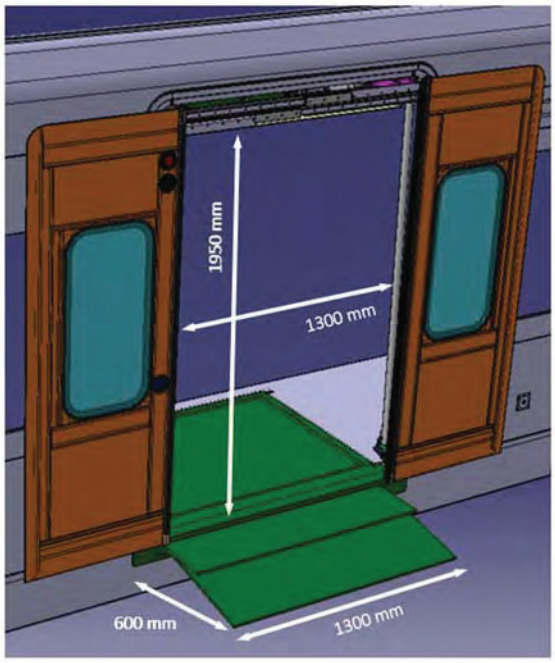

Figure 3 - Mock-up layout and clear passage dimensions [10]

Table 3 - Ramp/sliding step unit general dimensions

Element	**Size [mm]**
Ramp depth	1150
Ramp width	1395
Sliding part width	1300
Sliding step deployment	300
Ramp deployment	600

Apart from the sliding plate in the stowed position, the two different operations are respectively sliding step deployment and ramp deployment (Figure 5). In both cases, an integrated sensor system is capable of automatically utilizing the device as a gap bridge or as a ramp (Figure 4) without input from the end-user.

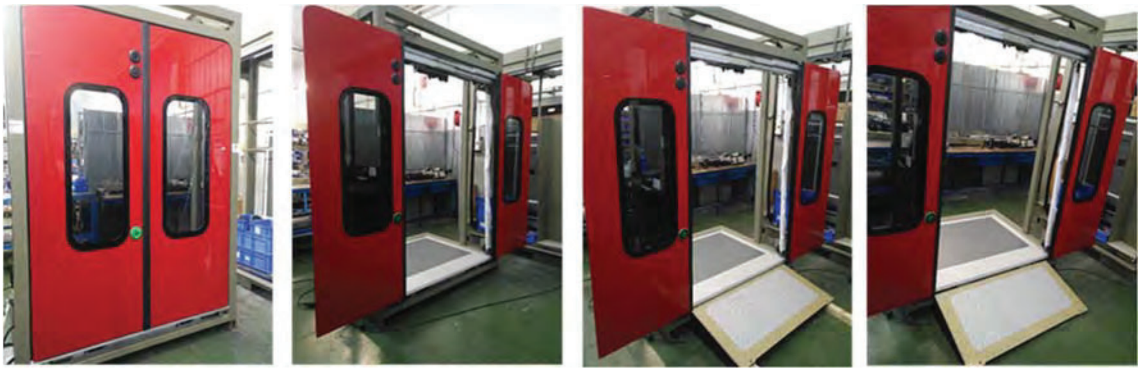

Figure 4 – Mock-up installed on-site at the manufacturer's plant (photo: Masats)

Such a sensor system can detect the position of the platform edge and deploy it accordingly (Figure 5).

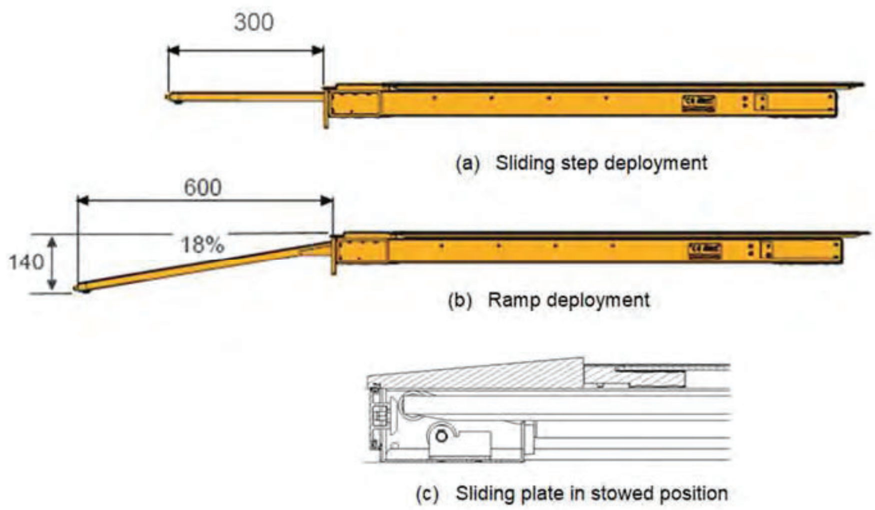

Figure 5 - Gap filler via sliding step or ramp mode [10]

Moreover, an obstacle detection system integrates the unit's main functions (Figure 6) achieved by two individual systems providing separate inputs: the first one is due to an overcurrent limit value monitored by the system during the plate deployment. Beyond this limit, this corresponds to an obstacle in the path. Besides, a sensitive edge installed at the front lip of the sliding plate can sense an impediment when it encounters it during the sliding plate/ramp deployment.

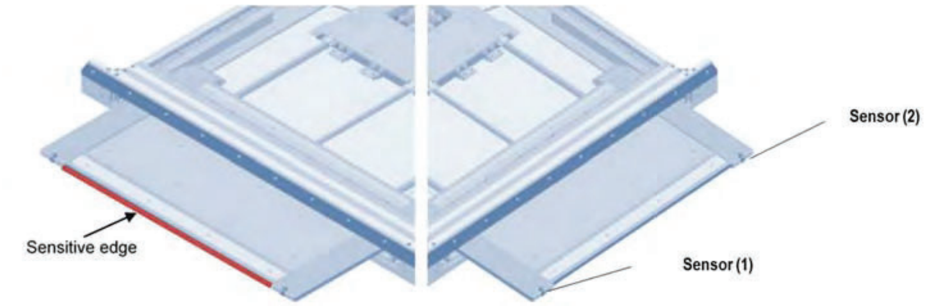

Figure 6 - Platform system detection [10]

In case of an overcurrent or a sensitive edge activation, the system can execute the following sequences:

1. The detected distance is < 300 mm: the sliding plate retracts 25 mm and execute another attempt to deploy it; after three negative attempts, the sliding plate retracts to the 300 mm position (gap filler mode);
2. The detected distance is ≥ 300 mm: the sliding plate retracts 25 mm and execute new attempts (after 3 seconds); after three negative attempts, the sliding plate retracts to 300 mm and remains extended as a gap filler.

In both cases, if the vertical distance between the sliding plate and the platform is < 40 mm, the system commands the plate to retract to the 300 mm position[5].

4 The experimental approach

The experimental tests will take place on the described mock-up provided by MASATS. The testing phase will engage a sample of around 20 individuals composed of persons with walking difficulties, people using manual or electric wheelchairs, visual impairments and parents with baby cars, selected among adult and young people, men and women, with different permanent or temporary disabilities.

The test plan includes the PRM sample definition, based on heterogeneity criteria for disability, age and gender, and a set of phases to steer the testing activity. Such steps include the efficiency and effectiveness of the prototype (i.e. mock-up and platform

[5] The reason of this limitation is to avoid crashing of the sliding plate should the train suffer a sudden change in its levelled position (i.e. a sudden loss of pressure in the secondary suspension system)

system) in pursuing reliability and safety targets under critical Boarding & Alighting (B&A) conditions. To this end, train access simulation takes into consideration the main parameters influencing accessibility from a human (e.g., disability, age, with/without the assistance of an accompanying person) and functional (height of the train platform) perspectives. The accessibility by small groups of people considers the following three specific criticality levels, simulated with replication of B&A procedures in different platform conditions to increase reality and reliability of trial tests:

- Low criticality Level (LL): one PRM boarding/alighting, without luggage;
- Medium criticality Level (ML): two PRM boarding/alighting, without luggage;
- High criticality Level (HL): three PRM boarding/alighting, with/without luggage.

The sample covers 5 clusters of permanent or temporary disabilities: visual impaired, people using crutches because of walking difficulties, manual wheelchairs users, electric wheelchairs users and mothers with baby strollers, each having a different size (the smallest are the visually impaired persons, followed by the parents with a stroller, while the largest refers to electric wheelchairs users).

Such tests include a minimum of three B&A cycles for each cluster of PRM and their combinations with replication for passengers boarding and alighting. By referring to the basic test scenarios, the various levels of criticality are as follows:

- Low Level (LL): three B&A cycles for each of the five PRM clusters, all passengers without luggage;
- Medium Level (ML): three B&A cycles for each combination without repetition of all pairs of the PRM clusters, all passengers without luggage;
- High Level (HL): three B&A cycles for each combination of all groups of three persons belonging to each PRM cluster, with or without baggage.

4.1 Expected timing for test activity completions

The total number of B&A cycles would be 165, distributed according to the three levels of criticality as follows:

- LL is composed of 5 x 3 = 15 single B&A cycles;
- ML is composed of 15 x 3 = 45 B&A combined cycles;
- HL is composed of 35 x 3= 105 B&A combined cycles.

However, by considering the actual size of each cluster, i.e., by referring to the real conditions, the number of B&A cycles could be slightly reduced for both the ML (from 45 to 42 B&A cycles) and HL (from 105 to 87 B&A cycles) criticality levels. The sequence and combinations of PRM clusters involved in each particular criticality level, as simulated through a specific number of B&A cycles, are in Table 4.

Table 4 - Sequence and combinations of real PRM sample for each criticality level

Criticality level	Test Features		Cluster ID	1	2	3	4	5
			PMR typology	VI	MB	CU	MW	EW
LL	N° involved people for each test	1	Sequence	1	2	3	4	5
	TOTAL N° of B&A cycles	15	n° of B&A cycles	3	3	3	3	3
ML	N° involved people for each test	2	Combinations	1+2; 1+3; 1+4; 1+5	2+2; 2+3; 2+4; 2+5	3+3; 3+4; 3+5	4+4; 4+5	5+5
	TOTAL N° of B&A cycles	42	n° of B&A cycles	3	3	3	3	3
HL	N° involved people for each test	3	Combinations	1+2+2; 1+2+3; 1+2+4; 1+2+5; 1+3+3; 1+3+4; 1+3+5; 1+4+4; 1+4+5; 1+5+5	2+2+3; 2+2+4; 2+2+5; 2+3+3; 2+3+4; 2+3+5; 2+4+4; 2+4+5; 2+5+5	3+3+3; 3+3+4; 3+3+5; 3+4+4; 3+4+5; 3+5+5	4+4+4; 4+4+5; 4+5+5	5+5+5
	TOTAL N° of B&A cycles	87	n° of B&A cycles	3	3	3	3	3

Table legend:
VI - Visually Impaired Person
MB - Mum with a Baby
CU - Crutches User
MW - Manual Wheelchair User
EW - Electric Wheelchair User

As far as the timings required for performing the tests is concerned, some assumptions on the lasting of both single and combined B&A cycles consider by single cycles, those involving only one person at a time and the combined ones, those involving 2-3 persons at the same time.

The estimated average time to run a single B&A cycle is 2 minutes, thus implying that LL should last 30-35 minutes. Moreover, the estimated average time to run each combined B&A cycle is 4 minutes, thus implying that ML should last 168 minutes.

Finally, the estimated average to run each combined B&A cycle with HL criticality is 6 minutes, thus implying that HL should last 522 minutes.

Considering the above levels of criticality, the basic test should last 725 minutes (12,10 hours), thought a prudential time to allow a smooth testing activity.

5 Closing remarks

Following the analysis carried out, it is clear that the accessibility requirement at the level of the train-platform system is essential for all railway passengers. Nevertheless, it becomes of crucial importance when it refers to PRM or, in any case, people with temporary or permanent disabilities to whom it is necessary to guarantee safe and, at the same time, comfortable train access. The confirmation of the topic's relevance also comes from the technological evolution concerning the boarding devices, namely ramps and gap fillers, allowing disabled people access and egress trains in an autonomous manner, echoed by the mandatory rules at the European level i.e., TSI expressly dedicated to PRM.

The concepts outlined in this paper, to be finalized through a demonstration activity, recall the testing procedure set up to define how to test accessibility and safety train passengers under diverse criticality levels by involving a heterogeneous sample of PRM. The demo activity will use a static prototype, which allows saving time and money and avoiding any risk due to the complexity of the real environment testing the boarding aid mounted in a real train stopping in a station.

A realistic forecast leads to suppose that the main results will likely deal with a lowering of time for autonomous PRM entrance within the train, an increase of accessing passenger comfort and a reduction of the train stopping time in the station compared to the situation of boarding equipment manually handled.

Anyway, the results of the demo activity matched with the findings of the conceptual one will be valuable feedback to improve the functional features of the ramp prototype and then translate them into design requirements. Besides, they will enable assessing the boarding equipment's feasibility. Finally, they will likely pave the way for future standards in onboard ramps construction to improve the interoperability of the train-station system at the platform level.

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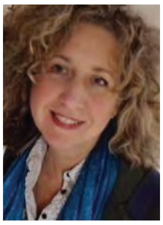

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