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Rail Vehicle Accessibility: Towards an Autonomous Train Usage for All Passengers

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Abstract

Accessibility is a key issue for all transport modes and becomes crucial with Persons with Reduced Mobility (PRM), to whom it is necessary to guarantee safe and comfortable train boarding and alighting. The methodology of this study is based on analytical and experimental issues. The first research effort focused on the design specifications of boarding aid to ensure the progress of theoretical concepts into practice. The second activity dealt with a prototypal demonstrator conceived as an adaptive device to bridge horizontal and vertical gaps between train and station platform. A panel of selected PRM tested the device's effectiveness, reliability, and safety. Starting from the design of the testing procedure, the paper describes the outcomes of the experimental activities in simulating and assessing the train accessibility for a heterogeneous sample of PRM.

Keywords: Railway platforms; gap filler; boarding aids; inclusive mobility; user-focus, Persons with Reduced Mobility.

1. Introduction

The train accessibility systems are strictly related to smooth train operating and passengers' safety. Despite the comprehensive implementation of the electric doors and related features (e.g., sensitive edge, push-buttons, slim design, etc.), such systems are still affected by a low level of reliability and safety, thus being one of the main components causing disruption and accidents (Dinmohammadi et al., 2016; Furth et al., 2006; Granström & Söderholm, 2005). The main factors that lead to the degradation of the rail access system can be actually traced to (1)

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the opening and closing movement of the door itself; (2) the vibration generated during the train running; (3) the sudden impact caused by the door encountering obstacles in the closing process and some other unexpected situations (Guo et al. 2020). In addition, failures in train access systems also result in delays on the line; in this regard, it is estimated that about 30% of delays on railways in Europe are due to door malfunctions (Monsuur et al., 2021).

Besides, such an issue becomes more critical if travelers are PRM. As there is no solution for their independent boarding, this requires cooperation between Infrastructure Managers (IM) and Railway Undertakings (RU) to manage assistance services for disabled passengers accessing trains. Such services, activated upon reservation, are always necessary for wheelchair passengers. In addition, booking must be made well in advance, thus precluding the PRM passenger from making short-term travel decisions.

According to the research lines developed within the EU-funded project CARBODIN, this paper describes the main outcomes of the experimental activities aimed at simulating and assessing the train accessibility for a heterogeneous sample of PRM. In doing so, the boarding aid conceived by MASATS and tested in a simulated environment is presented as a new solution that makes boarding and alighting movements autonomous for PRM. This solution is consistent with the PRM Technical Specification for Interoperability (TSI), where safe and obstacle-free access to rolling stock should ensure PRMs' dignity and integrity (Popović et al., 2009).

2. Literature review

It is commonly recognized that accessibility to infrastructure and service is a key issue in all mobility systems, regardless of the transport mode. Public transport accessibility has gained vital importance in designing and evaluating the transit system regarding mobility and sustainability (Saif et al., 2019). Besides, accessibility is commonly considered a potential, indicating the ease of performing specific movements or activities under various circumstances. Accessibility is founded on universal or inclusive design, which aims to remove barriers and provide an opportunity for everyone, regardless of ability. Its crucial role is enhanced in rail-based systems, understood as discontinuous systems only accessible in specific nodes, namely stations. Stations are the first interface between the rail and the land-side. A second inner level is the train-station platform system at the running plane. Both former and latter interfaces must be fully accessible to provide all rail users with a safe and comfortable travel experience (Piccioni et al., 2022).

Accessibility strongly affects passengers' perception of safety and comfort, especially those who encounter more significant problems when boarding and alighting the train due to their reduced mobility. When traveling by train, boarding and alighting (B&A) movements are ongoing challenges for PRMs. Moreover, there has been no standardization at the European level concerning the height of platforms or the width of the trains that stop at them. Indeed, some of the train's steps can be quite high, in some cases about double the height of a standard step. As a result, even if pathways from the station entrances, through the concourse, and to the platform are accessible, the distance between the platform edge and the train remains significant access and mobility hindrance for persons using electric or manual wheelchairs.

Many PRMs accessible train routes have personnel on hand to help disabled people in boarding and alighting maneuvers. Either a portable ramp or a portable wheelchair lift can be used (EMTA, 2005; EMTA, 2011). Most of these ramps and lifts are stored on the platform, usually chained to a post or a wall, thus meaning that PRMs need to ask a railway station staff to unlock them and provide assistance onto the train. For the above, it is evident that accessing the platform and the rail vehicle can act as a physical barrier to PRM, also causing a loss of social independence and employment opportunities (Swift et al., 2021).

3. The methodological approach

3.1 Setup of testing conditions

A double approach reflecting both the analytical and experimental issues characterized the methodology. On the one hand, to ensure that the theoretical concept could be fully developed and then translated into a real demonstrator, the first research activity included reviewing the design specifications (functional and technical requirements) of filling gaps in boarding equipment. Such a review considered the PRM TSI as a regulatory and technological focal point for improving the PRM accessibility to rail systems. On the other hand, further research dealt with a physical demonstrator: a prototype conceived as a new solution to fill the horizontal and vertical gaps between trains and station platforms. This prototype, namely a mock-up, is made up of the following two types of devices: (1) a gap bridge/ramp device (2 in 1); and (2) a complete door system composed of a door mechanism and two-door leaves (sliding/plug movement).

A simulator composed of a mock-up & a platform system (Fig.1) was then equipped to set up the scene, thus reproducing the various types of horizontal and vertical gaps.

Fig. 1. Masats simulator equipped with the (left) step; (right) gap filler.

Such a static apparatus was built at the MASATS manufacturer site (Barcelona/Sant Salvador de Guardiola, Spain) to simulate and assess train accessibility for PRMs with different platform designs. More appropriately, this prototype has been equipped with three platform-to-train interface variants; besides, an integrated sensors system detects the position of the platform, thus allowing the boarding aid deployment depending on the specific condition respectively, as shown in Fig 2: Ramp (T1); Step (T2); and Gap filler (T3).

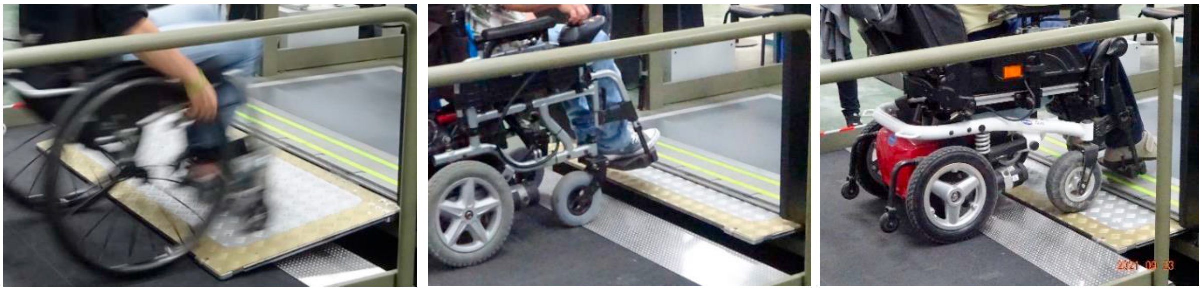

Fig. 2. Three-fold usage of the boarding device: (left) ramp; (center) step; and (right) gap bridge mode.

The sensoring system is the essence of the simulator. It adds the "intelligence," enabling the system to activate the boarding device's three-fold usage autonomously. It consists of a network of ultrasonic sensors positioned in the device chassis and moving plate. The information acquired by the sensors is relayed to the ECU (Electronic Control Unit), which governs and commands the operation. There are 2 groups of sensors: the former group *(A)* is located on the chassis, and their task is to detect the unit's position with respect to the platform level (Fig. 3). Depending on this information, the ECU decides whether to deploy the moving plate as a ramp, step or gap filler. It may also choose not to deploy the plate if the required conditions are not met. The number of sensors employed depends on the station platforms' geometry; if the platform edge is straight, only one sensor is used. For curved platforms, two sensors are integrated to provide a better measurement adjustment.

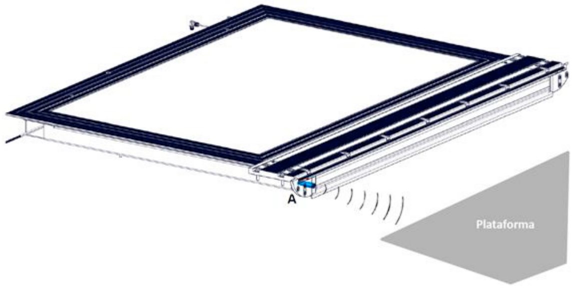

Fig. 3. The sensoring system: sensors belong to group A.

The latter group *(B)* is located on the lower surface of the moving platform, and its assignment is to detect the relative position of the platform level to the moving plate itself. As shown in Fig. 4, the sensors are positioned on both ends of the moving plate. The information is sent to the ECU, which decides whether the plate can be deployed as a step of a ramp. It also monitors the minimum distance necessary to allow safe deployment of the moving plate.

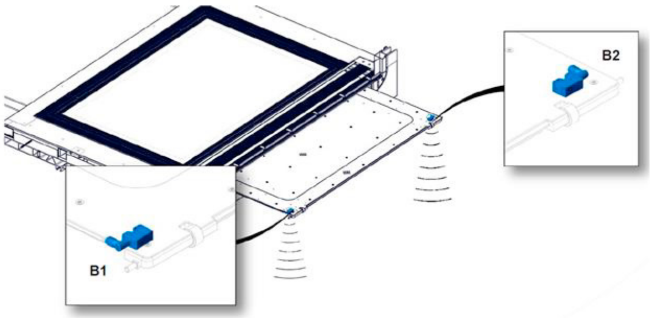

Fig. 4. The sensoring system: sensors belong to group B.

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 or at the level. From a functional standpoint, it compensates for a maximum vertical gap of 140 mm, while the maximum horizontal gap is 350 mm. It is worth stressing that due to the design parameters and the actual structure of the mack-up, the boarding device was tested by simulating the positioning of the train and platform system in a straight line (Piccioni et al., 2022).

3.2 Selection of criteria used for making up the PRM sample

The test plan included the PRM sample definition based on heterogeneity criteria for disability, age, and gender and a set of phases to steer the testing activity. Initially, the volunteers willing to participate in the testing phase were 20; however, due to Covid-19 health emergency and mobility restrictions, some people could not reach the MASATS premises. Consequently, the sample was sized to 11 individuals, composed of 1 visually impaired person (VI), 1 crutches user (CU), 4 manual wheelchair (MW) users, 2 of them with assistance needs, and 5 electric wheelchair (EW) users, to be arranged in 4 clusters of PRM. Accordingly, the testing phase engaged individuals with walking difficulties, people using manual or electric wheelchairs, and visual impairments, selected among adult and young people, men and women, with different disabilities. In doing so, the panel selection still maintained its heterogeneous features, thus ensuring the trial descriptiveness.

3.3 Testing phase development

The efficiency and effectiveness of the prototype (i.e., mock-up & platform system) in pursuing reliability and safety targets for train passengers were tested under critical boarding and alighting (B&A) conditions involving a heterogeneous panel of PRM. In such a case, train access simulation considered the main parameters influencing accessibility both from a human (i.e., type of disability, age, the need for assistance by an accompanying person) and a functional perspective (height of the train platform). The accessibility by a single person up to a small group of people, to be simulated with replication of B&A procedures, has been taken into account through three specific criticality levels, as follows:

- Low criticality Level (LL): 1 PRM person boarding/alighting;
- Medium criticality Level (ML): 2 PRM persons boarding/alighting;
- High criticality Level (HL): 3 PRM persons boarding/alighting.

Tests were based on a minimum of three B&A cycles for each PRM cluster and their combinations, based on the availability of the components, to replicate the procedures for loading and unloading passengers (Piccioni et al., 2022). More in detail, by referring to the testing scenario:

- Low Level (LL) of criticality: obtained by performing 3 B&A cycles for each of the four PRM clusters;
- Medium Level (ML) of criticality: obtained by performing 3 B&A cycles for each combination without repetition of all pairs of the PRM clusters;
- High Level (HL) of criticality: obtained by performing 3 B&A cycles for each combination of all groups of 3 people belonging to each PRM cluster.

The total number of B&A cycles would be 87, as shown in Table 1, distributed according to the following three levels of criticality:

- LL is composed of 4 x 3 = 12 single B&A cycles;
- ML is composed of 9 x 3 = 27 B&A combined cycles;
- HL is composed of 16 x 3= 48 B&A combined cycles.

Table 1. - Sequence and combinations of PRM clusters for each criticality level.

Criticality level	Test Features		Cluster ID PMR typology	1 VI	2 CU	3 MW	4 EW
LL	N° involved people for each test	1	Sequence	1	2	3	4
	TOTAL N° of B&A cycles	**12**	n° of B&A cycles	3	3	3	3
ML	N° involved people for each test	2	Combinations	1+2 1+3 1+4	2+2 2+3 2+4	3+3 3+4	4+4
	TOTAL N° of B&A cycles	**27**	n° of B&A cycles	3	3	3	3
HL	N° involved people for each test	3	Combinations	1+2+2 1+2+3 1+2+4 1+3+3 1+3+4 1+4+4	2+2+2 2+2+3 2+2+4 2+3+3 2+3+4 2+4+4	3+3+3 3+3+4 3+4+4	4+4+4
	TOTAL N° of B&A cycles	**48**	n° of B&A cycles	3	3	3	3

4. Performing the experimental activities

The testing activities took place across three days during the third week of September 2021. According to what is described in Section 3.2, the sample as a whole presents the following four clusters of disability, respectively composed of a person with visual impairment (VI), a person using crutches due to walking difficulties (CU), 4 users in manual wheelchairs (MW) and 5 users in electric wheelchairs (EW). The participants were instructed to move as if they were boarding or alighting from a real train. They started boarding and alighting by pressing the button on the door. People were waiting by the door until the door opening had been completed. The time measurements for B&A started from this moment until the participants finished the boarding or alighting maneuvers.

Because the time for the ramp deployment is not equal in different modes, the measured time for B&A is actually descriptive once subtracting the deployment times from their relevant measurements. Such deployment times were respectively 9 seconds for T1, 4 seconds for T2, and 5 seconds for T3.

Following the specific procedure set described in Section 3.3, the tests were carried out with three cycles for each PRM cluster and combinations based on the daily availability of the participants. The simulations were repeated for each ramp deployment scenario. Besides, the accessibility simulation of the Low criticality Level (LL), Medium criticality Level (ML), and High criticality Level (HL) were performed, thus implying that one, two, or three PRMs tried to board and alight simultaneously (Piccioni et al., 2022).

Due to limited available time and number of participants, along with the physical restriction of the train mock-up caused by its small standing area simulating the inner part of the train wagon, it was impossible to test all the 87 combinations of B&A criticalities. As a result, 50 B&A test runs in three different criticality scenarios were performed. Each boarding and alighting test run (two tests for each B&A cycle) was repeated and measured three times; thus, 294 boarding and alighting times involving PRM were computed to have an average value and calculate the standard deviations. Moreover, around 35-40 B&A tests without people's involvement were also conducted to verify the functioning of the train boarding aid in the three different device's deployment. It is worth underlining how the testing activities performed so far, albeit with the limits due to the sample size, provided outputs that can be considered sufficiently descriptive also from a statistical viewpoint. This aspect will be covered in the next section.

5. Discussion of results

The data collected from the testing activity allows for a thorough statistical study of PRM's boarding and alighting times per train door in different disability types and criticality level scenarios for a particular number of alighting and boarding passengers (Piccioni et al., 2022). The Student's t-test was performed to compare the mean B&A times and check if there was any statistically significant difference between the manual and electric wheelchairs. After completing the Student statistical tests on the EW and MW data, no statistically significant difference (p-value = 0.6) was observed between EW boarding and alighting time. However, the difference between the B&A times for MW users with T2 (step) and T1 (ramp) modes was significant (p-value < 0.05). The B&A times in T1 mode were not statistically higher than in the T2 mode, but the user experience was far better than in the step mode. The T3 (gap filler) mode provided the best comfort and accessibility and the lowest B&A times for manual and electric wheelchair users. A significant difference in the time spent between the train and platform occurred, considering the different device deployment modes for all PRMs (Fig. 5 and Fig. 6).

Fig. 5. Measured boarding times for EW and MW in all ramp deployment modes.

Fig. 6. Measured alighting times for EW and MW in all ramp deployment modes.

In particular, the EW and MW users experienced the most significant impact regarding door usage time, accessibility level, and comfort during B&A movements. It is worth pointing out that the T2 (step) deployment mode had the worst user experience for most participants, especially for the MW users with lower upper body strength, as one of the participants using a manual wheelchair could not board the train mock-up without assistance.
Even though the B&A for EW users was possible in the step mode, they experienced severe jolts during climbing and dropping from the 100 mm vertical gap existing in such a configuration.

During the T1 mode B&A tests, it became evident that the slope of the ramp makes the boarding movement for the MW users much harder than the EW ones, particularly for the volunteers with a lack of dexterity in their hands. The average boarding times for the MW users in ramp mode were reported as 3 seconds higher compared to their respective alighting times. On the contrary, the impact of different deployment modalities of boarding aid on VI participants' accessibility and B&A times was negligible (Fig. 7).

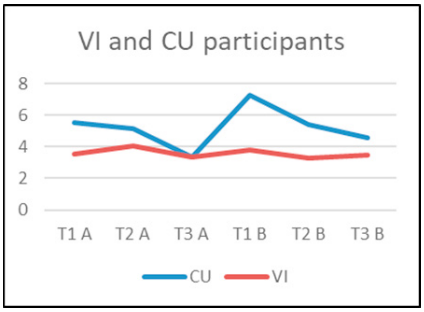

Fig. 7. Average B&A times for CU and VI people in different deployment scenarios.

Besides, for the CU participant, neither of the ramp modes was causing a significant problem for boarding and alighting movements; nevertheless, moving up the ramp slope appeared slightly more problematic.

6. Conclusions

This paper described the experimental steps in terms of methodological approach and practical one, affecting the train boarding equipment (i.e., ramps, step, and gap fillers) and provided the main finding linked to the B&A times as recorded during the test activities involving a heterogeneous sample of PRM.

Such activities lasted 3 days in September 2021, during which around 330-340 movements of the device were performed (294 of them handling PRM boarding and alighting cycles). No management problems or operational issues were detected during the demonstration phase. Based on the on-site testing activities conducted at MASATS premises, all the data collected across three days allowed for a comprehensive statistical study of PRM's boarding and alighting times per train door in different disability types and criticality level scenarios for a particular number of alighting and boarding passengers.

Once the Student t-test was performed on the EW and MW data, no statistically significant difference was observed between EW boarding and alighting time. However, the difference between the B&A times for MW users with step and ramp modes was substantial. The B&A times in ramp mode were not statistically higher than in the step mode, but the user experience for the former modality was far better than in the latter one. In addition, the gap filler mode provided the best comfort and accessibility and the lowest B&A times for all users.

The tested boarding aid device allows overcoming the current barriers, namely horizontal and vertical gaps between the door threshold and the platform, which hinder access and egress to and from the train for PRM. Moreover, it lets the end-user remove the responsibility of deciding whether it is necessary to deploy a ramp or a gap filler. Instead, the system decides what to do based on the platform geometry and layout. As a result, boarding of PRM and non-PRM people are managed the same way. It is also worth outlining how the solution proposed by MASATS embedded within the train wagon undoubtedly marks the first step towards autonomous or self-managed train access for all travelers without discriminating against those with walking difficulties or other types of disability.

The main outcomes of the experimental phase sound as helpful feedback to improve the functional features of the ramp prototype for translating them into design requirements. Besides, they enable assessing the boarding equipment's feasibility, thus paving the way for future standards in on-board ramps construction and further improvements of the interoperability of the train-station system at the platform level.

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