Technical Solutions for Means of Rail Transport in Improving Accessibility for People with Disabilities and with Reduced Mobility

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Abstract—The article includes an analysis involving the requirements for the adaptation of rolling stock for use by people with movement dysfunction. The requirements including construction and dimensions have been summarized and detailed conditions necessary to ensure the assumed level of travel comfort for people with reduced mobility with real examples of solutions used in currently operated railway vehicles. The focus was on the requirements set out in Regulation No 1300/2014 regarding technical design and construction solutions for adapting railways to the transport of disabled people, TSI PRM. Based on the collected material, an analysis of the compliance of the actual state with the theoretical one, included in the standard, was carried out. Elements designed and manufactured in a manner consistent with the recommendations contained in the standard, as well as those that require a re-analysis of rolling stock constructors, repair or necessary changes are indicated. The components analyzed included, among others, seating positions, movement zone - including internal and external doors, toilets or platforms enabling access to the interior of the vehicle The opinion of disabled people using rail transport was also included by conducting a survey and performing analysis and then interpretation of the data obtained. Basing on this analysis, solutions that will increase the comfort of travelling for people with disabilities have been proposed.

Index Terms—railway, polish transport, people with reduced mobility, TSI PRM

I. INTRODUCTION

Railway transport is now a very popular form of travel. According to data published in Forbes magazine - as many as 310.3 million people used rail transport in 2018, i.e. almost 7,000 more than in 2017 [1]. Such a large number of passengers is associated with a low fare and a high level of safety. It is also worth mentioning that this branch of transport is constantly being modernized, which significantly increases the speed of travel and comfort. Not only the rolling stock itself is developing, but also the infrastructure. Therefore, both fully functional and disabled people can use rail transport.

Disability is a widely understood concept, both in science and in law, and there are several types. These, in

turn, can be categorized into, for example, hearing, vision, movement dysfunction, heart disease, metabolic diseases, cancer, obesity or intellectual disability. Some are caused by acquired diseases, while others are simply birth defects [2]. Large proportions (about 45%) are mobilityrelated disabilities. A condition in which the motor skills of the body are significantly reduced directly affects difficulties in various areas of life. Based on data from the Labor Force Survey (LFS), in 2018 there were about 4.7 million people with disabilities, which accounted for just over 12% of the entire population in Poland [3]. These data, however, specify persons with documented disabilities who have a certificate.

Integrating people with disabilities into society is often dependent on mobility, so the demand for transport services in various European countries and the world is constantly growing. In the field of transport, appropriate steps have already been taken to facilitate the movement of people with disabilities. A number of technical solutions have appeared in land, sea and air transport [..].

Regarding rail transport, European railways have also focused their attention on solving the problem of transporting people with mobility impairments resulting directly from the maladaptation of railways to the disabled. In 1995, the Railway Institute began work on a program related to the adaptation of railways to transport people with mobility impairments. Among the many different activities aimed at facilitating the transport of the disabled, there were even the first structures of platform lifts (then with manual drive). These devices appeared at several of the largest stations in Poland. The projects have also repeatedly emphasized that not only rolling stock or infrastructure adapted to the needs of the disabled plays an important role, but also properly trained personnel [4].

Among passenger carriers in Poland, i.e. PKP Intercity, PrzewozyRegionalne, KolejeMazowieckie, KolejeMalopolskie etc., questionnaires were carried out regarding the number of rolling stock modernized for the transport of disabled persons (Fig. 1). As of December 31, 2016, out of 2,114 wagons - 104 were adapted for the transport of people in wheelchairs. The largest share in this is the company PKP Intercity, which owns 85 such wagons (which accounts for approx. 82% of all operated in Poland). In the case of electric multiple units, a

Manuscript received January 25, 2021; revised May 27, 2021.

significant part, as much as 34% of all trains were served by PrzewozyRegionalne (POLREGIO), while about 26% - by KolejeMazowieckie. PrzewozyRegionalne was also in the first place in terms of exploited combustion rolling stock. As at the end of 2016, the company had as many as 121 such warehouses, which represents about 63% of all vehicles of this type. On less loaded lines the company also used 2 electric motor cars [5].



Figure 1. List of rolling stock operated in Poland, division in terms of adaptation to the transport of persons in wheelchairs

The modernization of infrastructure has contributed to an increase in the number of disabled people using rail services. Analysing the data made available by the PKP company, the number of disabled passengers who were assisted in organizing rail travel was determined. In 2018, this number reached 19,840, of which as many as 6,945 people were in a light (manual) wheelchair, and 1,508 in an electric wheelchair. The list also shows 10 stations in Poland which served the largest number of people with disabilities in 2018. Warsaw came first, serving as many as 4,028 of these passengers, the second place with the number of disabled passengers 2,113 was taken by Poznan Głowny. Wroclaw Głowny was third, serving 2,021 people. Krakow was in the fourth place in this ranking. In 2018 alone, 1,587 passengers used the Krakow railway infrastructure [6].

II. LEGISLATION REGARDING THE ACCESSIBILITY OF RAILWAYS FOR PERSONS WITH REDUCED MOBILITY

These issues have become the subject of considerable interest among the European Union countries. When Poland also became a member state in 2004, cooperation began with the European Commission to develop laws on rail accessibility for people with reduced mobility [7]. This cooperation resulted in a number of laws and directives, as well as the introduction of certain devices to facilitate boarding and disembarkation of persons with disabilities. The most key documents that were entered in the White Paper include:

- Passenger Rights Charter;
- Regulation (EC) 1371/2007 of the European Parliament and of Rad of 23.10. 2007 (regarding the rights and obligations of rail passengers) -Chapter V of this document contains provisions regarding information that is made available by

railway undertakings, ensuring the protection of passengers and helping disabled people;

- Commission decision of 21.12.2007 (concerning the technical specification for interoperability regarding the aspect "Persons with reduced mobility" of the trans-European conventional rail system and the trans-European high-speed rail system;
- Commission Regulation (EU) No 1300/2014 of 18.11.2014 on the technical specification for interoperability in the field of accessibility of railways for disabled persons and those with reduced mobility TSI PRM,
- National implementation plan of the PRM TSI.

The regulation of 2014 - TSI PRM - has become one of the most important standards in the field of accessibility of rail transport forpeople with disabilities, and also the basis for the design and modernization of railway vehicles. Implemented on 01/01/2015, it applied to rolling stock and infrastructure of the rail system in all European Union countries [8].

In the field of rolling stock construction, the requirements contained in the PRM TSI relate, inter alia, to:

- Properly designed passages and doors,
- Seats and places for wheelchairs,
- Toilets,
- Information for disabled passengers.

The railway rolling stock is constantly being modernized, the carriers are also buying new passenger vehicles that are adapted to the needs of people with mobility impairments. An example of this is, for example, the signing of an agreement with the Center for EU Transport Projects for co-financing a project to modernize wagons and locomotives. By the end of 2023, PKP Intercity intends to allocate approximately PLN 7 billion for the purchase of new rolling stocks, modernization of existing ones and for the reconstruction of railway stations [9]. It is by far the largest investment program in the history of PKP Intercity. The modernized trains will be equipped with monitoring, air conditioning, comfortable seats and wireless internet. Above all, however, the rolling stock will meet the requirements for the transport of disabled persons. The Braille alphabet markings on the seats, which will significantly facilitate finding a place for the blind [10], are also worth mentioning.

III. REQUIREMENTS FOR RAILWAY VEHICLE ASSEMBLIES AND COMPONENTS ACCORDING TO TSI PRM

A. Movement Area

One of the most important elements of rolling stock is the space in which a disabled person would move. It is important to ensure that a wheelchair user can freely rotate 1800. The widths of individual corridors for wheelchairs are included in the TSI PRM Interoperability Specification. The relationship between the dimensions of a free passage and a perpendicular corridor that could be used by people in a wheelchair is shown in the table below.

TABLE I.	DIMENSIONS OF CORRIDORS ADAPTED FOR USE BY
PE	RSONS WITH MOVEMENT DISABILITIES [11]

The width of the free passage of the corridor [mm]	1200	1100	1000	900
The width of the free passage of the perpendicular corridor [mm]	800	850	900	1000

B. Exterior and Interior Doors Adapted for Wheelchair Users



Figure 2. Interior doorsadaptedfor people in a wheelchair (photo A. Lisowska)

An important element of the interior of the rolling stock is also the door. First of all, it should be marked in a way that contrasts with the surroundings. The same applies to the entire door control mechanism. Based on the standards contained in the TSI PRM, the doors can be divided into two groups - internal and external [11]. According to the design principles contained in Regulation 1300/2014, the width of interior doors should be not less than 800 mm in the open position. A very important aspect is that the transition adapted for people with disabilities should be located as close to their seats as possible. Moreover, this element should be designed in such a way that it is possible to operate the door automatically and the component responsible for control is located on the door leaf. As required, the door unblocking should be preceded by an appropriate - visible and audible signal. This sound, as required, should last not less than 3 seconds from the moment the door is opened. Similarly, it is the case with closing the door the signal should appear about 2 seconds before the mechanism starts and last during its operation. Exterior doors, in turn, are usually equipped with systems that would prevent a person using the passage from slamming inside. The usable width of this type of door should be not less than 800 mm, and the maximum force required to open it must not exceed 60 N. The mechanism responsible for controlling the passage must be between 800 and 1100 mm above the floor. The door (shown in Fig. 2 and Fig. 3) in the FLIRT vehicle meets the standards described.



Figure 3. Exterior doors adapted for the person in a wheelchair (photo A. Lisowska)

C. Seats

Currently, it is required that for 10 seats in the vehicle, at least 1 should be adapted for a person with mobility dysfunction, and also meet the same level of comfort as other seats in the railway vehicle. The number of seats adapted for persons with disabilities is strictly defined in the standards contained in the TSI PRM. Such seats should be located as close to the passage as possible to facilitate the traveler's movement (even to the toilet). Placing them at the shortest distance from the external door, in turn, makes it easier for a disabled person to get on board the vehicle. It is important to consider the free space above the seating position when designing a car for the disabled. It should be at least 1600 mm above floor level. The upper part of the chair should not be higher than 500 mm above floor level, while its total surface must be greater than 450 mm wide.



Figure 4. Seats for disabled people in one direction

The distances between two adjacent seats largely depend on their relative position. In a situation where the

seating positions are facing one way - the front surface of the back of one seat and the maximum vertical back of the other plane should be separated by a distance of not less than 680 mm. It is worth providing a free area of at least 230 mm between the edge of the seat and the aforementioned vertical plane. In the case of seats facing each other- it is important to consider an area not less than 600 mm between the seat edges when designing the interior of the vehicle. Arrangement of armchairs for disabled people is shown in Figs. 4 and 5. (1 - seat measurement level relative to the seat surface, 2 - the distance between seats, 3 - free space above the seat)



Figure 5. Seats for disabled persons facing each other

In trains designed in accordance with the TSI PRM standards, it is important to use space for passengers in a wheelchair. Appendix I of Regulation 1300/2014 presents individual schemes of places for wheelchairs (Fig. 6). There is only one wagon adapted for these travelers.



Figure 6. Place for a wheelchair (facing each other), (1 - structural element located at the end of the wheelchair space, 2 - the front edge of the passenger seat, 3 - wheelchair space)

For a train with a length exceeding 300 m, up to 4 places of this type are required, trains with a length of 205 - 300 m should be equipped with 3 seats for a disabled person, for a train with a length between 30 and 205 m - two seats, while in a vehicle shorter than 30m, there is only one armchair adapted for a person with mobility impairment. For reasons of stability during travel, this place should be designed in such a way that it can be turned backwards or forwards. The width of the space reserved for passengers in wheelchair should be 700 mm at least to a height of 1450 mm. Also, the 50 mm

wide space for the passenger's hand should be taken into account. The rear part of the space intended for a disabled traveler should be of suitable construction to prevent the wheelchair from tipping over. Opposite / next to the separated area there should be a seat intended for a companion or guardian of the person with mobility impairment. The space intended for a wheelchair user is shown in Fig. 7.



Figure 7. Space intended for a passenger in a wheelchair on a Stadler FLIRT train (photo A. Lisowska)

D. Toilets

Another important part of a railway vehicle that is required to be well adapted for a disabled passenger is the toilet. First of all, it should be in a wagon that is designed to transport people with mobility impairments. All controls both outside and inside the cab should be at a height oscillating within 800-1100 mm above the cabin threshold. It is also important to mark them properly - in contrast to the background. The width of the entrance to the toilet should be not less than 800 mm.



Figure 8. Toilet located in a wagon intended for people with motoric dysfunction (photo A. Lisowska)

It is worth mentioning that in the case of automatic or semi-automatic doors, partial opening should also be ensured. In such a situation, a person caring for a disabled passenger has the option of entering and exiting the cabin. It is also important that in the toilet on both sides of the toilet seat a handrail is attached, which would make it much easier for a disabled person to move to the seat from a wheelchair. The surface of the toilet seat should not be higher than 500 mm above the floor level inside the cabin. The interior of the cabin of a FLIRT vehicle is shown in Fig. 8. It is required that all the elements in the toilet are recognizable by touch and properly marked (in the form of pictograms).

E. Devices Enabling Boarding a Train

One of the most important elements of rolling stock construction in terms of its adaptation to transport people with mobility disabilities are all devices enabling boarding a train. There are various solutions for this type of systems, including movable steps mounted inside the vehicle and deck lifts. The latter are used precisely on the FLIRT train (Fig. 9).



Figure 9. A folded lift enabling a disabled person to enter a railway vehicle (photo A. Lisowska)

It is a subassembly fully integrated with the vehicle's external door. It is required that this device can overcome the maximum difference between the platform and the floor of the vehicle. Its acceleration during work may not exceed 0.3 g. For safety reasons, it is important to equip the lift with appropriate barriers that would prevent the wheelchair from rolling off the platform surface during movement. The elevator speed should not exceed 150 mm / s when lifting or dropping the passenger. The lift platform at floor level should not be less than 760 mm, while its length - 1200 mm. At the design stage of the device, it is necessary to consider the position of the wheelchair, back and front-facing the railway vehicle. It is also important to use contrasting marking on the lift.

F. Passenger Information Systems

One of the key elements is audio and visual information. Both apply to both disabled persons and other rail passengers. They should be located not only at the station but also on the surface and inside the train. When addressing the issue of information transfer, one should focus attention on messages transmitted visually, usually in the form of pictograms or signposts (shown in Fig. 10).



Figure 10. Identification of a wagon adapted for the transport of disabled persons (photo A. Lisowska)

It is important that the given elements contain unambiguous information - a ban, injunction, warning, marking of objects inside the rolling stock or even safety instructions. In addition, these signs should be designed in a legible and easy to understand way for people who use rail services. It is required that the symbols contrast with the surrounding background and use a sufficiently large font. In addition, it is worth paying attention to the SOS button (Fig. 11), located at seating positions, in the toilet and alarm intercoms located in a vehicle adapted for the disabled.



Figure 11. SOS button next to the wheelchair space

IV. SURVEYS REGARDING THE ADAPTATION OF RAILWAYS FOR PEOPLE WITH DISABILITIES

To thoroughly analyze the availability of rail vehicles for people with disabilities, a survey was conducted. The questionnaire with questions was placed on the website www.facebook.pl, in groups of disabled people with mobility problems and their carers. The condition of rolling stock in Poland was reviewed in terms of adaptation for the transport of persons with mobility impairment [12].

A. Research Group Analysis

Over half of those surveyed, as much as 51.5%, are between 20 and 30 years old. The reason is that this age group of people most often uses social networking sites, such as Facebook. Only 6.1% of people answering the questions are below 20 years of age, while above 40 make up 24.2%. 18.2% of people are in the age range 30 to 40 years old. Most, just over 75% of Facebook social network users answering the above-mentioned survey live in the city, while around 21.2% live in the countryside.

It is also worth mentioning that around 40% of those surveyed are actively working, while 24.2% are looking for a job. Just over 30% of the entire research group are students. The others are unemployed, among others due to their incapacity to practise a profession.

B. Assessment of Rolling Stock Availability for the Transport of Disabled Persons

Based on the results of surveys, it was also found that people with disabilities use rail transport services quite rarely. Most, as many as 63.6% of passengers asked, declared that they use the railway a maximum of 3 times a year (Fig. 12).



Figure 12. Frequency of using railways by respondents [12]

The factor affecting such a low frequency of train travel may still be the insufficient number of train sets adapted for the transport of persons with movement dysfunction or greater availability of other means of transport.

In the scale of assessing the availability of all rolling stock (and its individual components) from 1 (very poor) to 5 (very good), the respondents rated the vehicle condition slightly above average. 33.3% of travelers rated train adaptation at 3 (moderate), while 30.3% - at 4 (good).

Among the elements submitted to the opinions of Facebook users was a movement zone. At this point, respondents rated, among others corridor width. This aspect was also rated average. 36.4% of respondents were in favor of grade 3. This is also the case for opinions on internal and external doors. The respondents mainly described the problem occurring in old wagons, where the door is opened using a lot of force. In addition, people in a wheelchair mentioned too narrow passages between the cars, also in new trains. One of the respondents had a problem with free movement between the seats, despite moving in a wheelchair of a low width class.

The next area that was evaluated was the toilet. Both in unmodified and modern carriages, the biggest problem was the cleanliness of the room. As many as 30.3% of people rated this aspect as very poorly adapted and maintained. One respondent also added that the SOS buttons in the cabin did not work.

The aspect related to the availability of seating and wheelchair space was slightly better in the survey. 27.3% of disabled travelers (and their carers) rated the condition of this item as good, while 30.3% as average. The only problem that occurred in this area was the designation of the seating position in the compartmentless wagons. A visually impaired person had difficulty finding their place due to the hardly visible seat marking.

However, the worst assessed problem was the availability of devices for getting on and off the train. As many as 36.4% of respondents said that the availability of these elements leaves much to be desired. There was an connected only inconvenience not with their defectiveness but also with complete inaccessibility. The main problem with ramps and platforms, however, was the inability to operate them by the conductor crew. One of the respondents also complained about the lack of personal culture among assistants. Therefore, the assessment of the information flow was not satisfactory. either. Facebook page users talked about the counterintuitive system of buying a ticket for a guardian who would sit next to them during the journey. One of the disabled travelers mentioned the disappearance of his report, which caused confusion at the train station, and as a consequence - lack of assistance during boarding. A similar situation happened in the case of a person who declared their desire to travel only about 30 hours before the departure of a train. In connection with this, one of the respondents stated that shortening the time to prepare all organizational activities and equipment related to transporting a disabled person by rail would have a positive impact on the assessment of this aspect.

V. SUMMARY

The analysis of construction and design requirements, combined with a visual review of rolling stock elements related to improvements dedicated to disabled people, allowed for drawing some conclusions. The technical condition of the devices facilitating access to the train does not represent the required level. In this area, insufficient training of the conductor team and people operating these devices was also a problem. It would be worth focusing on improving this aspect. Similarly, in the case of other elements of the interior of a railway vehicle, such as a toilet. Here, in turn, an important role would be played by ensuring constant cleaning in the cabin. Improving the flow of information would also improve the assessment of rolling stock by disabled people.

In modern rail vehicles, people with disabilities are provided with a level of comfort that allows comfortable travel, but there are some shortcomings. Taking certain steps aimed at improving the technical condition and hygiene of components inside rail vehicles would significantly increase the popularity of this mode of transport among disabled travelers. The solution of shortcomings related to problem areas will first of all lead to an increase in the travel conditions of disabled people, and as a result, will enable re-analysis and development of further solutions affecting the increase of driving comfort.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Aleksandra Lisowska conducted the research and wrote the paper. Maciej Szkoda analyzed the literature and data. Both authors have approved the final version.

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