



## RAILWAY SYSTEM ACCESSIBILITY EVALUATION FOR WHEELCHAIR USERS: CASE STUDY IN THE CZECH REPUBLIC

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**Abstract.** This paper deals with accessibility of rail transportation as a system. Presented methods bring ways of rail infrastructure and train accessibility evaluation. Applied two-stage model enables evaluation of departure halls accessibility. The level of train accessibility is defined by coefficients of time and direction non-uniformity. While opportunities for barrier-free travelling are relatively balanced in monitored regions, coefficients show a time imbalance in the results. Opportunity to travel barrier-free (according to the non-uniformity coefficients) shows that there are fluctuations at weekends and on weekdays. These are not of crucial importance. However, the train services are barrier-free particularly for travelling on long distances, whilst suburban and regional ones are still mostly inaccessible for wheelchairs, which is not very favourable. Since 2010 the accessibility level has improved in this area in the Czech Republic. Comparison with neighbouring countries showed strong and weak points of guaranteed barrier-free services in each country.

**Keywords:** accessibility evaluation; barrier-free; passenger transportation; rail vehicle; railway infrastructure; railway transportation; wheelchair user.

### Introduction: Other Approaches to Accessibility of Public Transportation

Accessibility is a basic attribute of public transport. Accessibility can be defined in different ways, e.g. Cass *et al.* (2005) define 4 dimensions (levels) of accessibility (physical, financial/social, temporal and organizational). Orr (2010) deals with mobility of disabled and elderly people considering transport accessibility to be an important aspect of life quality for disabled people and elderly people at both macroscopic and microscopic levels.

The Author of this Paper understands the term 'Accessible public transport' as 'such status of public transportation system, which enables safe and independent access, adequate use for maximum time and safe movement without assistance to all people, including those with limited mobility and orientation'. Accessibility for people with limited movement and orientation is for Ozen (2010) one of the attributes of quality, sustainable public transport. On the other hand Das and Pandit (2013) do not mention any parameters important for people with disabilities among the 25 quality-of-service parameters for bus transport they refer to.

In this Paper the term 'accessibility' of public transport is further explained in the text related mainly

to wheelchairs. Visually impaired people are dealt with from a general point of view and in some particular cases. When we look at the focus of research activities of Ståhl *et al.* (2008), Andrews *et al.* (2012), Orr (2010), Wennberg *et al.* (2010), Shergold *et al.* (2012) and others, it is possible to say that there have been recent tendencies to turn attention away from disabled people to other groups with limited mobility, e.g. elderly people, mothers with baby carriages and small children.

Published results of accessibility research can be divided into several task groups. The first group deals with accessibility of transport itself: Chang and Chen (2012) or Bergel (2009) focus on air transport, airport accessibility and provided services for disabled people. Priorities of disabled and elderly people, accompaniment of children and baby carriages in bus service, interior of buses design requirements are researched by Pettersson (2009). Ståhl (1998) deals with accessibility of bus transport and special transportation services for disabled and elderly people in Sweden. The Swedish approach to accessibility, transport chains and influence of legislation changes on elimination of barriers in the city for disabled pedestrians and elderly people is solved by Wennberg *et al.* (2010). US transport accessibility from the point of view of Americans with disabilities act is



evaluated by Simon (1996). Stability and safety of carriages and scooters on the public transport buses during different styles of driving are presented in Turkovich *et al.* (2011). Safety of wheelchairs transported by special transportation services is evaluated in Wretstrand *et al.* (2004). Pavements and public areas create an integral part of the public transport system in cities. Their accessibility for elderly/disabled people in different seasons and removing of architectural barriers is dealt by e.g. Wennberg *et al.* (2010).

The other group of publications deals with social barriers and function of their elimination from public transport. Andrews *et al.* (2012) analyse the effect of 'free bus pass' for elderly people and its impact on elimination of social barriers in the UK. Shergold *et al.* (2012) present the influence of car property on mobility and activity of elderly people in rural areas. Geurs and Van Wee (2004) rank economic and social aspects of accessibility among important criteria for evaluating general accessibility of the public transport system. Ureta (2008) illustrates the social role of transport exemplified by the city of Santiago and its low-income inhabitants.

Many authors mention accessible travelling and tourism (tourist industry) as important market power and economical impulse for making attractive locations more accessible (Ray, Ryder 2003). Some of them research importance of training tourism students for work with disabled tourists (Bizjak *et al.* 2011). Possibilities of making selected destinations accessible for wheelchairs in New Zealand are dealt with in Lovelock (2010). Small *et al.* (2012) exemplify the results of an Australian survey, showing, apart from other things, that visually impaired tourists need not only accessible information, tactile ground surface indicators for movement with white sticks or proper illumination, colour contrasts, but also adequate approach of staff. Yau *et al.* (2004) analyse issues of accessible travelling for disabled people and the process of their gradual return to travelling. Lee *et al.* (2012) demonstrate that there is no specific relationship among barriers and intentions to travel for disabled people and confirm inverse relationship between the extent/type of disability and intention to travel. The results of the free time/recreational mobility survey in the area of Polish town Bydgoszcz, from the point of view of disabled people and their family members (without handicaps), are presented in Taylor and Józefowicz (2012). Information barriers and their elimination for disabled people in the area of tourism are solved by means of modern technologies in Winkler and Wöß (2006).

Making the environment accessible using application of modern technology (e.g. assistive geotechnology) for creating of more accessible environment for visually and mobility impaired people is dealt in Rice *et al.* (2012). Possibilities of increasing safety of visually impaired people at crossings when using advanced technologies and visible light communication technologies are mentioned in e.g. Suzuki *et al.* (2010).

Evaluation of rail accessibility in terms of guaranteed transport opportunities is very sporadic in the lit-

erature. Papers on rail accessibility e.g. Williams *et al.* (1995) or Brouder (1995), however, make an exception. Transport chains accessibility is also described in Wennberg *et al.* (2010). Blainey *et al.* (2012) deal with 37 different categories of barriers in rail transport from passenger's point of view and their importance, cost-effectiveness and feasibility of removing barriers.

Conception of street accessibility evaluation in the area of Malaysian cities is presented in Asadi-Shekari *et al.* (2013). Their model compares existing conditions with optimal requirements for disabled pedestrians. Output of evaluation process is 'disabled pedestrian level of service' for wheelchair users, visually impaired or elderly people on the city area.

This paper brings accessibility evaluation model which can be, after modifications, used for e.g. platforms, carriages, etc. This model and its application are presented on the case of accessibility evaluation of railway stations and stops in Pardubice. Second part of the paper presents the method of train accessibility evaluation using coefficients of time and direction non-uniformity. Both coefficients can be considered as partial criteria of public transport quality as their values show the level and opportunities to travel barrier-free on selected lines, and in the surroundings of selected regional cities. The coefficients were used for trains in this survey, but generally it is possible to apply them in other types of transport (e.g. regional bus transport). The aim of the research was to detect the level of opportunities for travelling barrier-free for wheelchairs compared to neighbouring countries. The results are presented in the chapters four and five of this paper. Previous research carried out in 2010 and show prospective changes in the field.

## 1. People with Disability and Accessibility in the Czech Republic and Abroad

In the Czech Republic, the term 'people with limited ability of movement or orientation' includes disabled, visually impaired, hard of hearing and mentally challenged people, together with senior citizens, pregnant women and people accompanying children up to three years of age or baby carriages. Unlike abroad, the Czech legislation does not involve people with reduced grip strength, concentration and perceptual disorders (e.g. in Germany) – see Verband Deutscher Verkehrsunternehmen (2012), people with allergies (e.g. in Sweden) – Šrámková (2006), people with short stature, and with large luggage or bicycles, who are included into this group by Commission Decision 2008/164/EC or Pettersson (2009).

In the Czech Republic there were about 9% of people with disorders (not including diabetics, epileptics and psoriatics), about 8% in Germany, 5% in Slovakia and about 9% in the US. According to the Office for Disability Issues (2011), 16% of the working age adults in the UK can be defined as handicapped. Presented examples show that this is not an insignificant number of public transport users and it is necessary to add another significant group of people 'without handicaps', who also use some barrier-free adaptations. European

statistics say there are about 30 per cent of people with limited mobility, and more than 15% of European population have a handicap. Other statistics say there are 5–20% of the population with disability in Asia (UN ESCAP 2000).

Different explanations of the terms ‘barrier’, ‘barrier-free’ or ‘accessible’, can be illustrated with the following examples of European countries, see Matuška (2009). Some countries (Germany, Austria, Spain, Croatia) define these terms relatively exactly by law. In the Czech Republic, Slovakia or Switzerland the explanation is very general or specified by technical standards. The author of this paper defines barrier as ‘any obstacle or condition that makes it difficult or impossible to use public transport adequately for people with limited movement and orientation.’ More about terms ‘mobility’, ‘accessibility’ see e.g. Orr (2010) or Stanley and Vella-Brodrick (2009).

In Spain and Norway, they use the terms ‘Universal Design’ or ‘Design for all’; in Norway they have applied translation of definition developed by the Centre for Universal design at North Carolina State University. The official Swedish definition does not exist. There is used terms ‘accessibility’ and ‘usability’. Czech Legislation related to public transport, especially railway, bus and mass urban transportation, obliges carriers to ensure that the transportation environment is accessible for people with reduced mobility and orientation, when technical conditions or capacity allow.

The study on accessibility of train connections in selected regions or agglomerations, conducted in 2010 (Matuška 2010b), was followed by a more detailed study and extended with a bus accessibility survey 2012 (to be published).

## 2. Barrier-Free Railway Transportation as a System

The author of this paper, as well as e.g. Wennberg *et al.* (2010), prefer a systematic and complex approach to the question of creating barrier-free environment in transport and transport chains. This requires accessibility of all subsystems, which create together the whole system of public transport. The subsystems of public transport include vehicles, infrastructure (buildings, public stops, railway platforms, etc.), information systems for passengers, carrier’s staff. It is also necessary to take into account links between individual subsystems, especially interactions between vehicle ↔ infrastructure, particularly the relation between the vehicle and platform edge (height difference, gap) or vehicle ↔ information system.

It is necessary to consider all phases of the transport chain when creating a barrier-free environment – from the start point (e.g. the place of living) to the destination. Barriers can occur on the access path to the public transport stop, when boarding, travelling and unboarding, on the access path to the departure halls, when gaining tickets, getting to platforms, boarding, travelling and unboarding the train at the arrival station and transport to the destination. If there is a barrier in any single phase of this chain, then the whole system of public transport becomes unattractive for passenger with disabilities.

If the accessibility of public transportation is going to be evaluated methodologically in a correct way, it is necessary to separate requirements of visually impaired, hard of hearing and disabled people. All three mentioned groups of barrier-free environment users have various and sometimes even completely different requirements for a barrier-free environment, transportation, orientation, communication, etc.

While wheelchair users can overcome steps or other height differences only when using technical aids (ramp, lifts, etc.), the stairs do not represent a barrier for the visually impaired (with white stick). The same situation exists when getting on trains. Visually impaired people recognize the gap between the vehicle and the platform edge using the white stick and usually can board without a problem, whereas wheelchair users cannot overcome the distance (bigger than about 10 cm) without help or other aids. Visible information is a barrier for visually impaired because they need acoustic information. This then represents an additional barrier for the hard of hearing person.

Another essential step in the accessibility evaluation methodology is to take into account all subsystems and links between them. This includes evaluation of accessibility of infrastructure (especially railway platforms, departure halls, terminals including access paths), as well as vehicles and information systems for passengers. Carrier staff getting into contact with passengers create an integral part of the system. They need to be trained to know rules of behaviour and attitude to passengers with various disorders. Analysis and its results presented in this paper were focused only on accessibility of railway system to wheelchair users, using models for accessibility evaluation of departure halls and train services. After modification of input data it is possible to apply the evaluation model for departure halls, railway platforms, railway cars or information systems for passengers.

### 2.1. Departure Halls

The essential precondition for usability of public transportation as a unit is accessibility and equipment of departure halls and areas for passengers at stations. It is necessary to comply with requirements for accessibility not only in the interior itself but also on the access paths to the departure halls, in the entrance area (door and immediate surroundings) and on the pathways to platforms.

Requirements for interior accessibility from the point of construction work, has been solved in a very satisfactory way e.g. in Zdařilová (2011) and most parameters comply with similar standards of neighbouring countries. The passing width (1.5 m, possibly 0.9 m) and handling area (1.5×1.5 m, minimum 1.5×1.2 m) are essential for wheelchairs. For example, at the booking office window and in front of the information boards or automatic ticket machine. A wheelchair accessible toilet is a fundamental requirement for 30% of wheelchair users mainly on rail long-distance journeys (Matuška 2011).

## 2.2. Railway Platforms

In the Czech Republic there must be at least one barrier-free access path to the railway platform for wheelchair users or visually impaired people. The height of the platform edge related to the train floor is an important parameter for wheelchairs too. There are three types of platform edge heights:

- 550 mm above the rail surface where the platform height corresponds to the floors in low-floor railway trains (550–570 mm above the rail surface). All new or refurbished island platforms and also side platforms must have this height. This is why we can find them especially in transit corridors and other railway tracks of national importance;
- 380 mm above the rail surface. This height is allowed only for platforms of selected stations and stops on single-track lines of regional importance;
- 200–250 mm above the rail surface. These are so called earth-filled embankments, platforms without solid edges – in small stations on regional tracks.

There are different heights of platforms abroad. For example in Germany, there are 4 different heights of platform edges: 380 mm and less (67%), 550 mm in regional rail transport (15%), 760 mm in regional and long distance rail transport and partly S-Bahn (13%), 960 mm and more on tracks with segregated operation of S-Bahn (6%). The data in per cents come from the year 2002 and refer to platforms operated by DB AG, see Verband Deutscher Verkehrsunternehmen (2012). In Switzerland the proportion of platforms with 550 mm above the rail surface exceeds 35% as shown in Dziekan and Ruhrort (2010).

Accessibility of pedestrian rail crossings is of high importance for level platforms accessibility too. Their parameters are mentioned in Rebstock and Wilde (2007).

## 2.3. Vehicles

As stated above, the height of the access area related to the platform edge is of crucial importance in railway accessibility for wheelchair users. In the Czech Republic it has been a recent trend in modernization of vehicles to take into account the relevant height of access areas or equip them with a wheelchair lift.

In the Czech Republic, the vehicles accessible for wheelchairs have the following floor heights:

- 550–570 mm above the rail surface – Czech Railways bought e.g. modernized diesel multiple unit ‘Regionova’, intended mainly for regional transport, double deck electric multiple unit ‘City Elephant’ for suburban and Regional transport or new diesel multiple units Regio-Shuttle RS 1 ‘Regio-Spider’ for regional transport;
- higher than 570 mm above the rail surface – e.g. electric multiple unit Pendolino for long distances (train category SuperCity), passenger cars of long distance in inland trains with adapted in-

terior (toilets, compartments adapted for wheelchairs). These are intended for regional and long distance transport. Some of these vehicles are equipped with a lift for wheelchairs;

- higher than 570 mm above the rail surface with interiors adapted for wheelchairs but without on-board wheelchair lift. To access these railway cars, it is necessary to use a mobile wheelchair lift. Czech railway stations have 85 mobile wheelchair lifts.

The horizontal gap between the platform and the vehicle is no less important for wheelchairs when getting on the train than the height of the platform edge. In the Czech Republic this gap is specified only indirectly by the Czech technical standard, establishing the platform offset  $l_{nh}$ . This distance depends on:

- location of the platform at the straight track, or in the curve of radius  $R \geq 1500 \text{ m} \rightarrow l_{nh} = 1670 \text{ mm}$  or in the curve of radius  $300 \leq R < 1500 \text{ m} \rightarrow l_{nh} = 1680 \text{ mm}$ ;
- width of the vehicles (low floor vehicles in the Czech Republic) ranges between 2820 mm (electrical double deck units ‘City Elephant’) and 3073 mm (diesel multiple units ‘Regionova’).

Presented examples show that the gap between the vehicle and the platform edge ranges between 133–270 mm in the Czech Republic, making it impossible for wheelchairs to get on independently and safely. This important parameter is explicitly set abroad, and depends on the height.

In Germany, the optimum values of the height and gap are 50×50 mm with possible max. deviation of one value by 50 mm as described by Verband Deutscher Verkehrsunternehmen (2012). In Switzerland this is optimally 50×50 mm, with an acceptable maximum deviation of 20 mm, which means maximum 70×30 mm (Horlacher 2012). In the UK, the values are set according to the Railway Safety Principles and Guidance, 40×35 mm (but the gap is up to 75 mm), Rail Vehicle Accessibility Regulations allow 75×50 mm. In the USA, the accepted values of the gap and height are 76×16 mm. However, there is an exception for existing platforms where the allowed difference in height can be up to 38 mm for one door of the vehicle with the gap of 76 mm. The gap of refurbished vehicles can be up to 102 mm with the height difference up to 51 mm as mentioned by Kühn and Braddock (2004).

Other important parameters for rail cars accessibility in the Czech Republic are the width of access door (850 mm), aisle width and passage to the area for wheelchairs (900 mm), dimensions and equipment of toilets. Czech regulations related to vehicles state that the vehicles shall be equipped with accessible toilet (without details concerning dimensions and equipment).

The above requirements and parameters are stated in technical standard for railways in the Czech Republic. Definition in more details – Commission Decision 2008/164/EC. Some parameters are new or different from the Czech ones, for example dimension and number of seats reserved for wheelchairs.

## 2.4. Information Systems for Passengers

Information Systems (IS) have become a necessary part of the accessible transport system adapted for wheelchair users or sight impaired people. In the Czech Republic, the national standard for designing accessible information systems has not been specified yet, which leads to considerable disunity of IS characteristics.

The Commission Decision 2008/164/EC is valid in the EU/EEA member states. This Decision, apart from other things, solves the requirements for information systems in vehicles, and therefore it is binding on the Czech Republic. The Internal Directive of the Railway Infrastructure Manager, coming into existence since January 2013, will set parameters and requirements for designing and using railway information systems. The Author of this Paper has been participating in the amendment procedure.

The important things for wheelchair users are the location of devices like buttons, keyboards, etc., which are allowed to be placed up to a height of 1200 mm. Readability of displayed information depends on the size, contrast and brightness of the font and background (Parry 1995). To set the values of contrast or font size and some other properties (speed of dynamic text, etc.), it is possible to use Commission Decision 2008/164/EC, because Czech methodology does not yet exist.

## 2.5. Staff

Other important aspect of barrier-free public transport is knowledge of carrier's staff in the area of communication, assistance for wheelchairs, hard of hearing or visually impaired people. This is something that the national rail carrier Czech Railways is aware of, and therefore the staff who are in contact with passengers have been trained in this field. Internal regulations of the Czech Railways have contained, for several years, instructions on how to offer help to a wheelchair user, visually impaired or hard of hearing person and how to treat and communicate with these people. In mass urban transportation the application of a similar approach is less successful and therefore the situation is very unsatisfactory in bus transportation.

## 3. Evaluation of Railway Station Accessibility

Accessibility of railway stations and stops for disabled people is one of the important requirements for accessibility and attractiveness of rail transportation as a system. The stations and stops in the Czech rail network are classified according to accessibility of departure halls (three categories), platforms (four categories) and toilets (three categories). This classification has been carried out by the Czech Railway Infrastructure Manager. Another way of public building (e.g. banks, offices, schools, theatres, museums, stadiums, etc.) classification into three categories is being created now under supervision of Prague Wheelchairs Organisation. Both ways of accessibility classification evaluate how the parameters comply with relevant standards.

Unlike above mentioned classifications, the two-stage evaluation model designed by the Author, takes into consideration importance  $\delta_i$  of individual factors  $H_j$  for wheelchair users. The following factors (critical points – see Matuska, 2010a) are very important for wheelchair users at railway stations and stops: access path to the station or stop, entrance, interior, toilet, information systems for passengers (obtaining tickets).

Accessibility level of one building (e.g. station) is expressed by coefficient  $\beta_0$ . To determine its value, two steps have to be carried out.

*In the first stage* it is necessary to define and evaluate factors of building accessibility  $H_j$ . The access path to building –  $H_1$ , entrance –  $H_2$ , interior –  $H_3$ , toilet –  $H_4$  and information systems (obtaining tickets) –  $H_5$  are of key importance for wheelchair users. Each of these five factors is – based on analysis – evaluated by value (integer) from interval  $(-1;3)$ . Value '-1' implies barrier or absence of any equipment. Positive values reflect a certain level of accessibility. The exact values of  $H_j$  are given as a result of parameter analysis – degree of compliance with standards and regulations.

Value three – all elements correspond to requirements of standards and regulations. Barrier-free access path to the building with width min. 1.5 m, in slope maximum 1:12; entrance without level changes or max. 0.02 m, door width min. 0.9 m. Interior without level changes, free area in front of important places (information stand, window, etc.) 1.5×1.5 m (minimum 1.2×1.5 m); barrier-free toilet (incl. route designation and relevant logo).

Factors with minor problems in accessibility level for wheelchair users (e.g. unpaved access path, low step in entrance area, restricted access to information/counter, WC without logo, etc.) are evaluated as value two.

Factors with significant problems (e.g. complicated or restricted access path to departure hall, hinge door, interior with barriers or level changes without lift) are evaluated as value one. Negative value '-1' signifies barrier environment near or in interior of the departure hall or missing barrier-free modification (entrance with steps, inaccessible WC, etc.).

Negative value indicates non-appropriate state of accessibility and it reduces total value of building accessibility.

*In the second stage* the importance (weight)  $\delta_j \in (0;1)$  of individual factors  $H_j$  was defined:

$$\sum_{j=1}^m \delta_j = 1. \quad (1)$$

Values of  $\delta_j$  were defined upon results of investigation, which was carried out among wheelchairs in 4 Czech middle size/big cities. Wheelchair users evaluated importance of each factor – from 1 (not important, least important) to 5 (most important). Individual values of  $\delta_j$  were defined by applying rank method. Access path:  $\delta_1 = 0.07$ ; entrance:  $\delta_2 = 0.33$ ; interior:  $\delta_3 = 0.27$ ; adapted WC:  $\delta_4 = 0.20$ ; information/obtaining tickets:  $\delta_5 = 0.13$ .

Accessibility coefficient  $\beta_0$  for one building (e.g. departure hall) is given by (2):

$$\beta_0 = \sum_{j=1}^m \pm H_j \cdot \delta_j \quad [-] \quad (2)$$

Coefficient  $\beta_0$  reaches values from the interval  $\beta_0 \in \langle -1; 3 \rangle$ . Author suggested four categories of departure hall accessibility:  $\beta_0 \in \langle -1.0; 0.5 \rangle$  inaccessible;  $\beta_0 \in \langle 0.5; 1.5 \rangle$  accessible with restriction;  $\beta_0 \in \langle 1.5; 2.5 \rangle$  almost accessible;  $\beta_0 \in \langle 2.5; 3.0 \rangle$  fully accessible.

For analysing  $n$ -buildings ( $n$ -subsystems) it is necessary to modify formula from (2) to (3):

$$\beta = \sum_{i=1}^n \sum_{j=1}^m \pm H_{ij} \cdot \delta_{ij} \quad [-] \quad (3)$$

and output values  $\beta \in \langle -n; 3n \rangle$ . The rating of system accessibility (intervals – see above) is analogical to evaluation of one building.

An example of departure hall accessibility evaluation for wheelchairs (applying two-stage evaluation model) is railway stations and stops in Pardubice area (Čtvrtečková, Matuška 2005) – see Table 1.

The Table 1 shows rating of two stations and six stops. Both stations have a very good level of accessibility  $\beta_0 = 3$  and 2.93. One stop is almost accessible ( $\beta_0 = 1.53$ ) and other one is accessible with restriction ( $\beta_0 = 1.34$ ). Four stops cannot be evaluated positively as they do not have accessible toilet, entrance and interior for wheelchairs. The last line of the table presents supplementary information about the individual factors: access paths and information systems are completely accessible for wheelchair users, while toilets are not easily accessible.

The presented two-stage evaluation model can also be used for accessibility evaluation of other parts (subsystems) of railway system, especially railway infrastructure – platforms, vehicles, information systems for passengers. Assessment of values  $\delta_j$  of each important factors  $H_j$  present necessary condition for applying this model for accessibility evaluation of more subsystems.

#### 4. Railway Transport Accessibility in Regions

Evaluation of railway infrastructure accessibility by the two-stage evaluation model is described in previous chapter. The results of train accessibility analysis, carried

out in five regions, provide documentary evidence of the actual possibilities of travelling by train for wheelchair users in the Czech Republic. The largest urban agglomerations – Prague, Brno and Ostrava have been intentionally omitted. These cities/agglomerations are specific also in the area of barrier-free transport, and thus they would distort the real situation.

Railway accessibility was surveyed in the Liberec, Hradec Králové, Pardubice, Vysočina (Regional City Jihlava) and Olomouc Regions (Fig. 1). There are about 200–290 thousand inhabitants in each regional city and towns lying on analysed lines. The only exception is Vysočina Region with low density of population (about 130 thousand inhabitants). People commute to all these five regional cities for work, education, health services, culture, sport and leisure activities. The expert study by Matuška (2010b), helped to compare the changes in railway accessibility in these regions during two years.

Monitoring numbers (proportions) of trains designated in the Timetable 2012 by the Carrier as accessible for wheelchair users was conducted as part of the evaluation. Trains on 23 routes from and to the regional cities were monitored on working days and at weekends. The working day was represented by Wednesday, and weekend by Saturday (mostly). Evaluation included direct suburban connections, regional and distant trains stopping at stations within 11–52 km (on average 28 km) radius of the regional city.

The data (numbers and proportions) are related to the time period of the whole day (0–24 h) and arranged

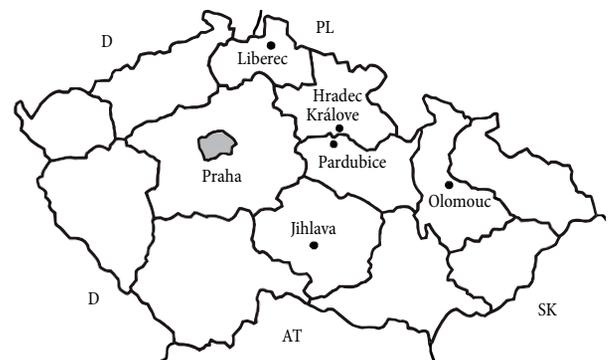


Fig. 1. Analysed regions

Table 1. Evaluation of railway stations and stops in Pardubice area

Station/stop	Access path	Entrance	Interior	WC	Information/ticket	$\beta_0$
Pardubice hlavní nádraží	3	3	3	3	3	3.00
Pardubice–Rosice	2	3	3	3	3	2.93
Pardubice–Pardubičky	2	2	2	–1	3	1.53
Pardubice–Semtín	2	1	3	–1	2	1.34
Pardubice závoďišť	1	1	–1	–1	1	0.06
Pardubice–Svítkov	2	1	–1	–1	1	0.13
Pardubice–Opočínec	2	1	–1	–1	1	0.13
Pardubice–Černá za Bory	2	1	–1	–1	1	0.13
$H_j$ rating	16	13	7	0	15	

into tabular summary (Table 2), presenting detailed information on proportion of barrier-free trains on individual railway lines. The number before the slash represents numbers of accessible trains; the number after the slash is a total number of trains in the area surrounding the regional city, distinguishing directions, weekdays and weekends.

Table 2. Proportion of accessible trains in the Czech Republic

Station	Weekday		Weekend	
	from	to	from	to
<i>Liberec</i>				
Turnov	18/18	18/19	18/18	19/19
Jablonec	25/25	25/25	25/25	23/23
Frýdlant	26/26	26/26	18/18	18/18
Hrádek	26/26	26/26	19/19	19/19
Jablonné	10/17	11/17	9/16	10/16
<i>Hradec Králové</i>				
Pardubice	11/43	11/40	10/41	10/33
Jaroměř	11/37	11/37	11/26	11/27
Chlumec	1/27	1/28	5/21	5/22
Týniště	8/26	8/29	7/17	7/17
Jičín	12/15	12/15	6/8	8/10
<i>Pardubice</i>				
Hradec Králové	11/40	11/43	10/33	10/41
Chrudim	19/28	24/24	18/23	17/18
Choceň	6/42	5/41	5/34	4/37
Kolín	26/61	25/61	22/58	22/57
<i>Jihlava</i>				
Havlíčkův Brod	2/16	2/16	2/11	2/10
Horní Cerekev	7/19	7/18	8/13	8/15
Třebíč	8/16	8/16	10/16	10/14
<i>Olomouc</i>				
Zábřeh	9/47	9/46	10/47	10/46
Senice	17/17	17/17	9/9	9/9
Prostějov	2/27	2/25	3/27	2/25
Přerov	2/45	2/45	1/36	1/37
Domašov	14/14	14/14	15/15	14/14
Uničov	17/22	17/22	14/14	13/14

#### 4.1. Liberec Region

There are all together 5 railway lines starting from the Regional City Liberec. These operate passenger, express and fast trains. The monitoring covered the trains within 21–38 km from Liberec and about 202 thousand citizens in towns and cities where the analysed trains stop. The analysis results show that the trains on most railway lines are barrier-free, either on working days or at weekends. The proportion of barrier-free trains is between 59–100% on weekdays and 56–100% at weekends. This means that this region is among the top regions in the Czech Republic.

#### 4.2. Hradec Králové Region

There are all together 5 railway lines commencing from this regional city in Eastern Bohemia and about 255 thousand inhabitants in important cities on the lines. The analysis includes trains between towns and cities within 17–52 km (on average less than 22 km). The analysis results show that the proportion of barrier-free trains of most tracks surrounding Hradec Králové is between 4 and 80% on working days or 23 and 80% at weekends.

#### 4.3. Pardubice Region

The fast trains stopping in 4 important stations (Choceň, Kolín, Chrudim, Hradec Králové), on average within 27.5 km from Pardubice have been analysed. The number of inhabitants on the lines reaches 275 thousand. Proportion of accessible trains on railway lines surrounding Pardubice is between 12 and 100% on working days and from 11 to 94% at weekends, and shows a substantial fluctuation.

#### 4.4. Jihlava Region

This region is of low density of population, there are only 130 thousand inhabitants in urban areas on analysed lines. The analysis included the trains stopping at stations Havlíčkův Brod, Horní Cerekev and Třebíč. Average distance of these stations from Jihlava is about 32.5 km. Proportion of accessible trains on railway lines surrounding Jihlava is between 13 and 50% on weekdays, 18 and 71% at weekends. Most barrier-free trains operate between Jihlava and Třebíč. However, there is a minimal possibility to travel barrier-free between Jihlava and Havlíčkův Brod (which is an important center of the region and a railway junction).

#### 4.5. Olomouc Region

The analysis covered trains on 6 railway lines converging to Olomouc or trains going to/from important stations Zábřeh, Senice, Prostějov, Přerov, Domašov a Uničov within 19–46 km (on average 27.5 km) and about 293 thousand inhabitants in cities lying on analysed lines. The number of barrier-free trains in this region fluctuates a great deal too: 2 railway lines offer full barrier-free operation (100% accessible trains), 1 line has 77–100% of barrier-free trains and the proportion of barrier-free trains on remaining 3 lines is very low (3–22%).

#### 4.6. About Supply and Demand for Accessible Trains

It is possible to ask whether the offer of guaranteed barrier-free trains is sufficient or not. How many journeys do wheelchairs make? The survey by Follmer (2004) deals with this question. This investigation focused, apart from other things, on daily mobility of disabled people in comparison with mobility of people without disabilities. The results of this survey show, that people without disability make 3.4 journeys daily, whereas disabled people 2.95 on average. Although disabled people have almost the same demand for travelling as other people, the supply of guaranteed accessible trains is (in the Czech Republic, Slovakia) disproportionately lower than for people without disability.

### 5. Train Accessibility Evaluation

Author designed coefficients of direction  $K_d$  and time  $K_t$  non-uniformity in order to evaluate accessibility of the trains.

#### 5.1. Coefficient of Direction Non-uniformity

Coefficient of direction non-uniformity  $K_d$  expresses the balance between the number of accessible trains on specified railway lines from and to the given city. It is set as a quotient of difference between the number of accessible trains (in one and the other direction) to the total number of accessible trains on given railway lines – see formula (4):

$$K_d = \frac{|A_1 - A_2|}{N_{TA}} \quad [-], \quad (4)$$

where:  $A_1$  is a number of accessible connections of the railway line in one direction (to the regional city);  $A_2$  is a number of accessible trains on the same railway line in the opposite direction (from the regional city);  $N_{TA}$  is the total number of accessible trains in both directions;  $K_d = x; x \in \langle 0, 1 \rangle$ . The lower the value the coefficient reaches, the more balanced the number of accessible trains in both directions becomes. If  $K_d = 0$ , the number of accessible trains in both directions is equal. If  $K_d = 1$ , accessible trains run only in one direction, which then represents a considerably unattractive opportunity.

#### 5.2. Coefficient of Time Non-uniformity

Coefficient of time non-uniformity  $K_t$  expresses the time distribution of accessible connections during the day. The  $K_t$  values presented below show the results of accessibility analysis (the number of accessible trains on specified tracks) in the period 0:00–11:59 and 12:00–23:59. The formula below is valid for  $K_t$  coefficient calculation (5):

$$K_t = \frac{|n_m - n_a|}{N_{TA}} \quad [-], \quad (5)$$

where:  $n_m$  is a number of accessible trains in the morning, in the time period 0:00–11:59;  $n_a$  is a number of accessible trains in the afternoon, in the time 12:00–23:59;  $N_{TA}$  is a total number of accessible trains in the 24-hour time period;  $K_t = x; x \in \langle 0, 1 \rangle$ . Similarly to  $K_d$ , the lower the value  $K_t$  reaches, the more time-balanced it becomes.  $K_t = 0$ , which means a balanced offer of accessible connections in the morning and in the afternoon, and when  $K_t = 1$ , it expresses a situation where accessible

trains run only in the morning or in the afternoon. To be objective, it is necessary to note that morning covers the time period of about 7–8 hours while afternoon’s period covers about 10–12 hours.

Table 3 summarises results of analyses in specified regions and enables inter-regional comparison of rail accessibility on weekdays and at weekends, as well as comparison of direction and time balance. The values in [%] are rounded to whole numbers and values of coefficients to two decimal places.

The best situation of rail accessibility is in the Region Liberec (on working days, as well as at weekends). In Pardubice, Jihlava and Olomouc Regions the accessibility is balanced on weekdays. The second in accessibility is Jihlava Region (at the weekend). Pardubice, Jihlava and Olomouc Regions are quite balanced on working days.

The best time-distribution of accessible connections during the day ( $K_t$ ) is reached in the Region Liberec, either at weekdays or weekends. Considering the direction distributions ( $K_d$ ), the same possibility to travel barrier-free is in Regions Hradec Králové, Jihlava and Olomouc. The absolute balanced possibility to find accessible connection can only be found in the Region of Jihlava. The direction non-uniformity coefficient reaches very good values in Region Liberec.

#### 5.3. Comparison within the Year 2010 and Abroad

As mentioned above, a similar survey was conducted in 2010, but the results were far from favourable. The level of accessibility can be illustrated by the fact that the best of the Czech regions (Liberec) at that time offered only 46% of barrier-free trains and that was higher than average regarding other analysed regions and the overall situation in the Czech Republic.

Fig. 2 shows changes in train accessibility on weekdays during the 2 year period. Apart from Jihlava Region, it is possible to say that the situation has substantially improved during the mentioned time. Barrier-free accessibility to the rail system on weekdays has improved by 15% (from average 31% to 46%).

The largest increase of accessibility, by more than double, has been again in the Liberec Region, which then belongs amongst the top regions in all the Czech Republic. Equally, the proportion of accessible trains has increased more than double in Hradec Králové Region. Yet this region remains among the least accessible of all monitored regions.

Table 3. Accessibility of trains in the Czech Republic

Region	Accessible [%]		$K_d$		$K_t$	
	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
Liberec	94	94	0–0.05	0–0.05	0.08–0.27	0.11–0.26
Hradec Králové	29	37	0	0–0.14	0–1.00	0–0.43
Pardubice	37	36	0–0.12	0–0.11	0.09–0.67	0–0.50
Jihlava	34	51	0	0	0–1.00	0–1.00
Olomouc	36	34	0	0–0.20	0–1.00	0–1.00

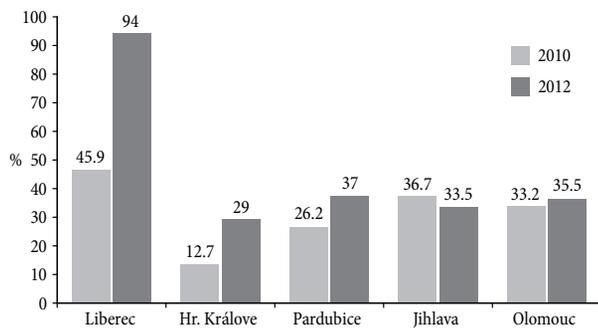


Fig. 2. Comparison of train accessibility on weekdays

Comparison of guaranteed barrier-free trains in the Czech Republic and abroad was performed in two neighbouring countries – Slovakia and Austria. Analysis was carried out on fifteen rail lines in Bratislava, Žilina, Banská Bystrica and Košice Regions (Table 4).

Table 4. Accessibility of trains in chosen regions of Slovakia

Station	Weekday		Weekend	
	from	to	from	to
<i>Bratislava</i>				
Kúty	7/25	7/25	6/20	6/20
Trnava	14/44	14/41	12/30	12/35
Galanta	5/25	6/24	4/20	4/25
Komárno	0/24	0/25	0/18	0/19
<i>Žilina</i>				
Považská Bystrica	11/26	12/26	11/23	12/22
Čadca	7/26	7/25	7/21	7/21
Rajec	0/11	0/11	0/7	0/6
Kralovany	7/24	7/26	7/19	7/19
<i>Banská Bystrica</i>				
T. Teplice	1/8	1/9	1/6	1/7
Zvolen	2/28	2/29	2/22	2/23
Brezno	1/15	1/14	1/11	1/11
<i>Košice</i>				
Margecany	7/25	7/23	7/20	6/18
Moldava	2/9	2/9	2/8	2/8
Hidasnémeti (H)	0/2	0/2	0/2	0/2
Trebišov	4/10	4/10	3/8	3/8

The analysis of guaranteed trains for wheelchairs in Slovakia shows:

- the way of marking guaranteed trains in Timetable is the same as in the Czech Republic;
- contrary to the Czech Republic, only long distance trains are guaranteed in Slovakia, although low-floor multiple units are operated in neighbourhood of cities Žilina, Košice and Bratislava;
- contrary to the Czech Republic, the number of guaranteed trains on weekdays and weekends is not of a big difference;
- coefficient of direction non-uniformity shows very little values, it signifies practically identical

possibility to travel to/from regional centres for wheelchair users;

- coefficient of time non-uniformity shows values comparable to the Czech Republic.

Eleven rail lines and guaranteed trains were analysed in Austria in the surroundings of cities Linz/Donau, Salzburg and Villach for the purpose of comparison (Table 5).

Table 5. Accessibility of trains in chosen regions of Austria

Station	Weekday		Weekend	
	from	to	from	to
<i>Linz/Donau</i>				
Summerau	13/13	14/14	12/12	11/11
St. Valentin	39/43	41/44	35/38	37/40
Neuhofen/Krems	30/30	29/29	22/22	24/24
Wels	63/81	74/95	56/74	67/77
<i>Villach</i>				
Arnoldstein	15/17	13/14	10/12	9/11
Hermagor	10/10	11/11	8/8	8/8
Klagenfurt	16/21	16/21	14/20	16/21
St. Veit/Glan	9/10	10/11	9/11	10/11
Spittal-Millstätter See	9/15	9/16	5/12	9/16
<i>Salzburg</i>				
Neumarkt	13/18	17/24	12/17	13/20
Golling-Abtenau	19/24	17/23	17/22	17/22

Analysis of monitored rail lines shows:

- the way of marking guaranteed trains is similar to the Czech Republic and Slovakia but in some cases it is necessary to book the wheelchair journey in advance in mobility centre;
- suburban, regional and long-distance trains are guaranteed for wheelchair users;
- only low-floor multiple units are operated on many regional lines; guaranteed trains proportion is 70–93% on average, except for e.g. line Villach–Spittal with 58% on weekdays and 49% on weekends;
- guaranteed trains proportion difference between working days and weekdays are similar to Slovakia;
- coefficient of time non-uniformity shows relatively big difference.

## Conclusions and Discussion

The conducted analysis and comparison of accessibility level in 2010 some foreign countries show that infrastructure accessibility (especially departure halls, platforms, public transport stops) can be evaluated by the two-stage evaluation model which takes into account important critical points (Matuška 2010a) as well as their importance for disabled people.

Barrier-free accessibility of the rail system has improved substantially during the last two years, especially

due to purchasing new or refurbished diesel multiple units and electric units, and passenger cars for long-distance transport that is equipped for transporting wheelchair users. Accessibility of railway transportation is direction balanced (shows only minimum fluctuation) which enables wheelchair users to travel there and back. This represents a quality improvement in comparison with last years, when barrier-free connections were sporadic and it was no exception to find a barrier-free train in only one direction once a day.

Opportunities of barrier-free connections in the mornings, afternoons and evenings show larger fluctuation. On four tracks, barrier-free trains run only in the morning or afternoon, either weekdays or weekends, which makes railway transport rather unattractive for wheelchair users.

Opportunities for travelling on weekdays and at weekends are relatively balanced for wheelchair users. Increased proportion of barrier-free trains at weekends in Hradec Králové Region (+8%) and (+17%) Jihlava Region is only apparent because it is caused by decreased number of all connections, while the number of barrier-free connections remained the same (in Jihlava Region slightly increased) compared to weekdays.

Three regions (Hradec Králové, Jihlava and Olomouc) have, on some railway lines a majority of accessible trains belonging to the category fast train or EuroCity/InterCity. It follows that there is a very limited opportunity for using barrier-free regional passenger trains to the suburban areas.

To evaluate railway transport objectively in the regions, it was necessary to take into account also the accessibility of stations and stops on the analysed railway lines. Particularly this area is currently most unsatisfactory. The majority of regional lines have platforms inconvenient for boarding and the un-boarding of wheelchair passengers (height, width). So these stations are still inaccessible for wheelchair users without assistance. Liberec and Hradec Králové Regions, have only one mobile wheelchair lift each. Pardubice Region has 5, Jihlava Region 11 and Olomouc Region 7 mobile wheelchair lifts. Railway station Jihlava is accessible only in

a limited way for wheelchairs; whereas the other four stations meet the requirements for accessibility.

For a comprehensive evaluation of the overall possibilities of barrier-free travelling, bus connections in the Region need to be taken into account as well. Barrier-free bus services have substantially improved in some regions. Considering the number of guaranteed barrier-free buses, the top regions are Liberec and Jihlava, while, on the contrary, Hradec Králové, Pardubice and Olomouc have rather sporadic guaranteed accessible buses. Unlike the railway transport, the opportunity of barrier-free connections depends on particular carriers and their strategies of bus fleet renewal.

Although the proportion of guaranteed barrier-free trains in the Czech Republic has gradually increased due to big investments into rolling stock modernization, proportion of guaranteed trains in monitored Regions is about 48% while in Austria it is 82% and in Slovakia about 22% (Table 6 and Fig. 3).

Comparison with Slovakia and Austria shows one common aspect of all three countries: time non-uniformity of guaranteed barrier-free trains. The essential difference lies in the offer of guaranteed barrier-free trains: in Slovakia only long-distance trains are guaranteed barrier-free, unlike Czech Republic and Austria.

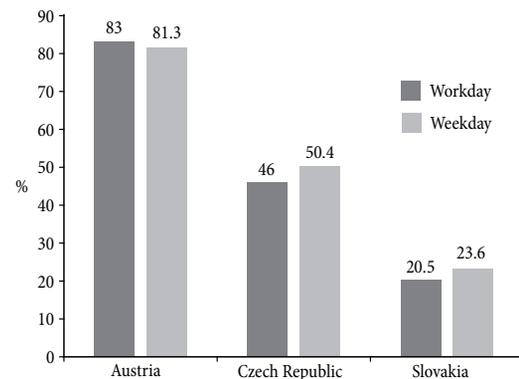


Fig. 3. Guaranteed accessible trains proportion in Austria, Czech Republic and Slovakia

Table 6. Trains accessibility comparison in Slovakia and Austria

Region	Guaranteed accessible [%]		$K_d$		$K_t$	
	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
<i>Slovakia</i>						
Bratislava	21	24	0	0–0.09	0–0.30	0–0.25
Žilina	25	30	0–0.04	0–0.04	0–0.30	0–0.30
Banská Bystrica	8	10	0	0	1.00	1.00
Košice	28	29	0	0–0.14	0–0.50	0–0.50
<i>Austria</i>						
Linz/Donau	92	93	0.02–0.08	0.03–0.09	0.18–0.34	0.15–0.22
Salzburg	74	73	0.06–0.13	0–0.04	0.13–0.27	0.20–0.29
Villach	83	78	0–0.07	0–0.29	0–0.22	0.06–0.26

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