DETERMINING THE EXTENT OF USABILITY OF TACTILE WALKING SURFACE INDICATORS

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Abstract:
The paper focuses on usability of guiding lines and tactile features which enable the visually impaired to move safely and independently in facilities designed for transport. On a transport terminal example, the authors, with the help of Fuzzy logic, model the degree of these modifications usability for all passengers. In the mathematical model, the input information takes advantage of Fuzzy sets which do not include sharp edges and are influenced by the real fragmentation of the given terminal´s space and the intensity of transport streams. When creating the model, firstly, input and output variables, including the values which can increase, are specified. Then, a set of rules is formulated, based on individual user groups´ specific experience. The users are divided into six basic groups: fully mobile persons, persons with reduced mobility using compensatory aids, visually impaired persons, persons with hearing impairment, persons with mild mental disabilities, and non-native speakers. The resulting outputs of the Fuzzy model are various degrees of usability of tactile features specified for the defined user groups.

Keywords: Public transport passengers, disabilities, Fuzzy logic, tactile walking surface indicators (TWSIs)

1. Introduction

Passengers using public transport move in real environments of transport terminals, departure halls and arrival halls. These facilities are perceived by them through their sense priorities, this perception is dominantly visual, acoustic or tactile. A large percentage of the whole amount of passengers are persons with limited mobility or orientation. Severely visually impaired persons cannot drive cars, and therefore they are frequent users of public passenger transport. Despite all modern supplements, their mobility is still dominantly dependent on the "long white cane" technique, which is helpful for their independent mobility and spatial orientation. The accessibility of transport infrastructure should be logically in compliance with the two-sense rule for information systems. For persons with visual impairment, the visual information is transformed into audio and tactile information. (Decree No. 398/2009 Coll.), (DIN 18040-3, 2014), (Barrierefreier ÖPNV, 2012). In case of waiting rooms of transport terminals´ departure halls, visually impaired persons´ mobility is affected mainly by the disposition complexity, distribution of obstacles along natural guiding lines (Košťálová, Matuška, 2016), convenient lighting, acoustic elements of the information and guiding system, spaces without undesired flaring surfaces and without mirroring. All these also depend on the intensity of the transport streams and noise burden in the given space. In case of existing transport facilities, which are often included in the system of the cultural heritage preservation, it is not easy to additionally install aesthetic and functional tactile elements convenient for visually impaired persons. Moreover, the usability and sustainability of these additional adjustments and their financial demands are the essential factors for owners of and investors into the facilities.

The authors of this paper decided to apply Fuzzy logic to evaluate the rate of usability of specific adjustments aimed at safe and independent mobility of all persons. There is a qualitative gap between the knowledge obtained through the natural cognitive process and the knowledge obtained through the exact science method. Fuzzy logic helps to overcome this gap (Křemen, 2007). This advanced method of managerial decision-making is used by the authors for evaluation of the real usability of "tactile indicators on a walkable area" in relation to all passengers. The tactile indicators concerned were specifically designed for visually impaired persons´ independent and safe mobility. The elements individually perceived in a given space are exactly evaluated when using practical experience and knowledge.

The set theory defines a set as a group of elements of certain properties. The given element either belongs or does not belong to a particular set. This means that only these two conditions can develop. L. Zadeh created the theory of fuzzy sets and fuzzy logic, in which it is determined how much such an element belongs to a set, and the element is defined within the range of <0,1>; where 0 means the complete non-membership and 1 means the complete membership. Fuzzy logic thus measures the certainty or uncertainty of the elements´ membership in a set. This is similar to the process of people´s decision making in the sphere of mental and physical activities which are not fully algorithmic (Dostál, Rais, Sojka, 2005). The processing in Fuzzy systems requires three basic steps – fuzzification, inference and defuzzification.

- *Fuzzification*: conversion of real variables into linguistic variables and their application into fuzzy sets with the determination of the degree of membership, determination of the membership function shape, transformation of the input data into the predetermined range <0,1>.
- *Inference:* inferential mechanism and creation of the rule basis < IF >, < THEN > on the linguistic basis, determination of the support degree, that means the weight of the rules.
- *Defuzzification*: conversion into real values, resp. conversion of fuzzy sets into the sharp output value which specifies the membership in the set in the best possible way (Dostál, 2008).

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2. Usability of tactile indicators (TWSIs)

The amount of the offered information and distribution of its sources must be logical. The excessive amount of information (e.g. of an acoustic kind) results in excessive psychical stress imposed on a visually impaired person. On the contrary, the absence of important information, e.g. in a large departure hall or on a platform, devalues the whole system of adjustments (Matuška, 2014). If there are too many tactile elements close to each other in a small space, a contrary situation develops. A person with severe visual impairment is not able to distinguish one individual element from the other individual elements, and a smaller waiting room turns into a critical space (see Fig.1). Then, such a kind of adjustment of the floor (quite frequently a historic one) does not work in case of visually impaired persons. Moreover, it is not safe for people with reduced mobility and quite often it is even not aesthetically matching the original architectural style (see Fig.2).

Fig. 1.
TWSI in passenger hall, Kanazawa (Japan)

Source: L. Nakagoshi

Fig. 2.
TWSI before stairs, Kanazawa (Japan)

Source: L. Nakagoshi

2.1. Research into perception of space

The authors of the paper applied Fuzzy logic with the aim to provide a mathematical expression of the rate of usability of tactile indicators on a walkable area. The input data needed for the mathematical model were obtained from the research survey based on the questionnaire specially designed by the authors (Košťálová, 2018). The survey was carried out in the time period from June 20th to June 21st 2018 in selected railway stations during the assumed afternoon rush hour. 162 respondents participated in the survey, our priority efforts were made to address as many age groups as possible. The results were used for dividing the passengers into fuzzy sets and determining the degree of the membership, and the priority type of the spatial perception applied by the individual groups of users. To make the real situation simplified, two types of the assessed space´s size were considered. One type was represented by departure halls with the size over 8 × 8 m, the other type was represented by waiting rooms of light dimensions up to 8 × 8 m. The authors applied the standard systems of load bearing structure of transport facilities in the Czech Republic and, simultaneously, they considered testing of blind persons´ ability of walking in the straight line. The distance of 8 metres is the limit distance within which a blind person keeps his/her moving direction in a straight line with a minimum desired deviation (Decree No. 398/2009 Coll.), (Zdařilová, 2011). The results of practical measurements on road crossings and in the public space are used for making the walk of persons with severe visual impairment safe (Suzuki et al. 2010).

Selected outputs from the aforementioned research are presented below for illustration (Košťálová, 2018, Fig. 3, Fig. 4).

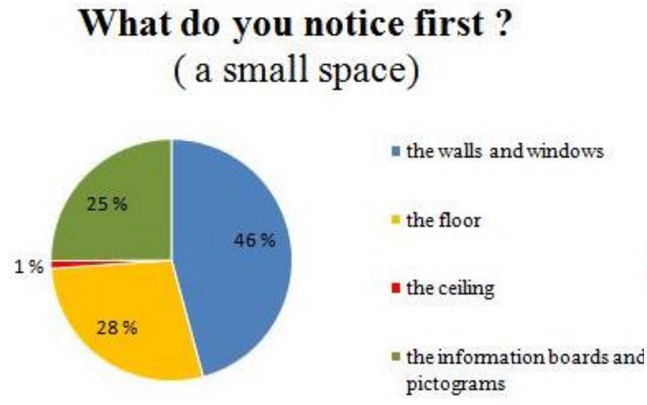
***Types of passengers** (given in percentage):*

Persons without moving restrictions (79 %), person using compensatory aids (7 %), persons with baby strollers (4 %), persons in wheelchairs (3 %), persons with hearing impairment (3 %), persons with severe visual impairment (2 %), persons non-familiar with the language or written characters (1 %), persons with mild intellectual disabilities (1 %).

***Age of the passengers** (given in percentage):*

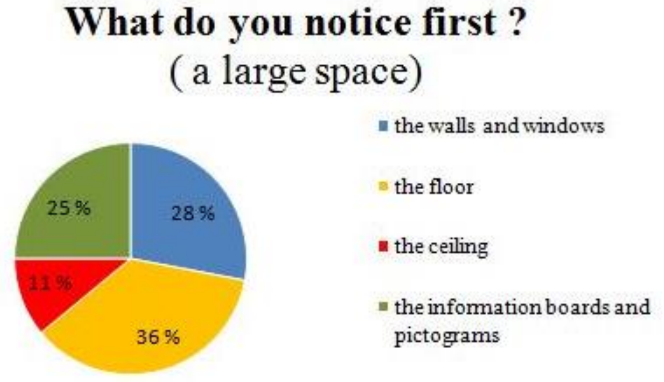
From 6 to 12 (1 %), from 13 to 17 (17 %), from 18 to 26 (26 %), from 27 to 45 (13 %), from 46 to 65 (22 %), from 66 to 80 (20 %), over 80 (1 %).

Fig. 3.
Perception of small space within a small space



Source: Košťálová, 2018

Fig. 4.
Perception of small space within a large space



Source: Košťálová, 2018

2.2. Classification of passengers

Processing in the MathWorksMATLAB program was carried out with the support given by the Fuzzy LogicToolbox and Mamdani´s regulator.[3] When creating the model, we first specified the input variables including the range of their values. Users of the transport infrastructure and facilities can be divided into several groups (Barrierefreier ÖPNV, 2012), (Matuška, 2014). However, every person is unique and has a differently long reaction time when a stimulus appears. Physical maturity and psychical maturity are also important. Dividing the passengers into strictly given categories based on the existing norms and decrees can never fully correspond with reality (Decree No. 398/2009 Coll.), (ISO 21542:2011), (DIN 18040-3, 2014). Every person can be defined through a mathematical combination of individual limitations. To make the calculation process realizable, the authors applied a simplified model of an assessed person. To make the situation better understandable, we can give an example of a person who suffers from Diabetes of the 2nd type. The primary disease is further complicated by secondary issues; these complications have an impact on the primary disease development. A relatively healthy person is gradually changing and is showing a bigger number of potential disabilities. In case of the worst complications, the person is gradually becoming blind, and very often his / her limb amputation is necessary (see Tabs. 1, 2).
Concerning the behaviour of passengers in transport facilities, some groups logically merged during processing of the model, individual limitations were simplified and the transport streams´ intensity was neglected in the considered size of the space. In the FIS Editor, four input variables were chosen: PD (mobility impaired passengers), VP (visually impaired passengers), HP (hearing impaired passengers, deaf and dumb passengers), MP (mentally impaired persons and persons not familiar with the language and written characters), and then one output variable - UVL[4] = TWSI[5] (evaluation of the usability of a tactile indicator) - was chosen (see Tabs. 1 – 5).

Table 1
Classification based on mobility limitations and disabilities

MOBILITY /PD/		Classification according to function
Mild mobility disabilities and temporary limitations:	- Persons accompanying infants up to the age of 3 in baby strollers, - pregnant persons - heart diseases, venous diseases, etc.	**0 – 0,3**
Moderate disabilities:	- canes, crutches, walking sticks	**0,2 – 0,5**
	- rollators, walkers	**0,5 – 0,75**
Severe disabilities:	- mechanic wheelchair, three-wheel electric scooters - electric wheelchair, handbike	**0,75 – 1,0**

Source: Košťálová, 2018

[3] **MATLAB**: License Number: 40 62 77 67, E-mail domains: tul.cz, Release: 2018 a, TECHNICAL UNIVERZITY OF LIBEREC, THE FACULTY OF ART AND ARCHITECTURE, Department of buildings, Ing. J. Košťálová.
[4] UVL artificial guiding lines in Czech Republic = TWSI.
[5] Tactile walking surface indicators.

Table 2
Classification based on visual limitations and disabilities

VISION /VP/		Classification according to function
Dioptric **eye-glasses**	- defects corrected with diopters	**0 – 0,3**
Persons with low vision: *Classification according to the WHO* [6]	- moderate low vision	**0,2 – 0,5**
	- severe low vision	**0,5 – 0,6**
	- severely severe low vision	**0,6 – 0,7**
Blind persons	- practical blindness	**0,7 – 0,8**
	- complete blindness	**0,8 – 1,0**

Source: Košťálová, 2018

Table 3
Classification based on hearing limitations and disabilities

HEARING AND SPEECH (impact on spatial orientation) / **HP/**		Classification according to function
Minor **hearing and speech defects**:	- correction with hearing aids	**0 – 0,3**
Remnants of hearing:	*Classification according to the WHO*	**0,15 – 0,75**
The deaf:	*Classification according to the WHO*	**0,75 – 1,0**

Source: Košťálová, 2018

Table 4
Classification based on mental and cultural orientation

MENTAL AND CULTURAL ORIENTATION influencing the spatial orientation / **MP/**		Classification according to function
Non-familiar with the culture, mild retardation:	without the knowledge of the language and written characters, IQ 50 – 69 / feeble mind, senility	**0 – 0,3**
Medium retardation:	IQ 35 – 49 / debility, oligophrenia, imbecility	**0,3 – 0,75**
Severe retardation:	IQ 21 – 34; IQ < 21 is not considered Sub-normality, idiocy	**0,75 – 1,0**

Source: Košťálová, 2018

Table 5
Usability of tactile indicators

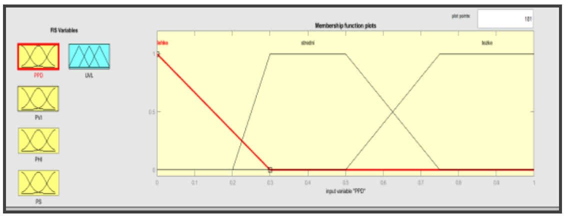
TACTILE INDICATOR (TWSI) = UVL	Classification according to function
Unused:	**0 – 0,2**
Partly used: intuitive	**0,2 – 0,525**
Fully used:	**0,525 – 1,0**

Source: Košťálová, 2018

2.3. Fuzzy system

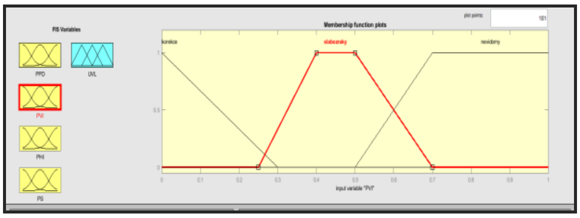
Variables and membership functions were set in a detailed way in the Membership Function Editor.

Fig. 5.
Mobility limitations and disabilities



Source: Membership Function Editor

Fig. 6.
Visual limitations and disabilities

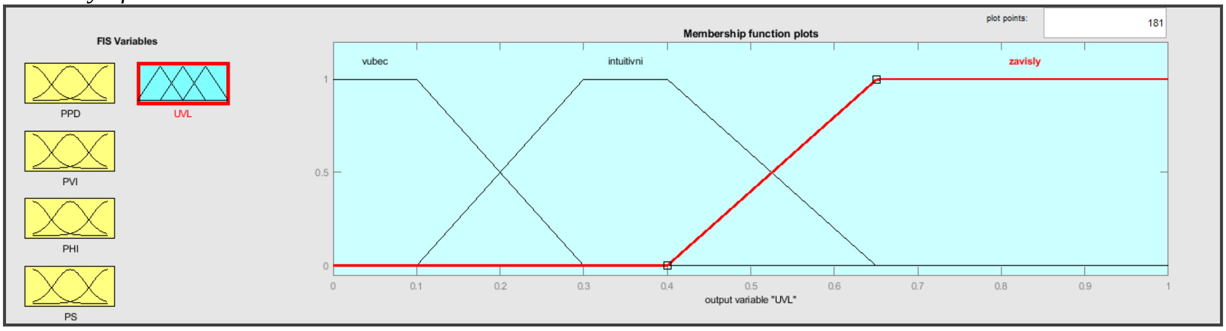


Source: Membership Function Editor

[6] WHO: World Health Organization

The decided range was in ten parts in the interval <0,1>. See Tabs. 1 – 5. In case of each group, the triangle and trapezoid shapes of the functions *L* and *Z* were used, depending on the limitations and disabilities. See Figs. 7 – 9.

Fig. 7.
Usability of a tactile indicator



Source: Membership Function Editor

The next step was to formulate the basis of rules resulting from the specific user groups´ experience and from the aforementioned research results. The inferential rules based on real situations and potential combinations of various disabilities were set into the Rule Editor. Our model involves 25 rules which are most frequently applicable in the real environment (see Fig. 8).

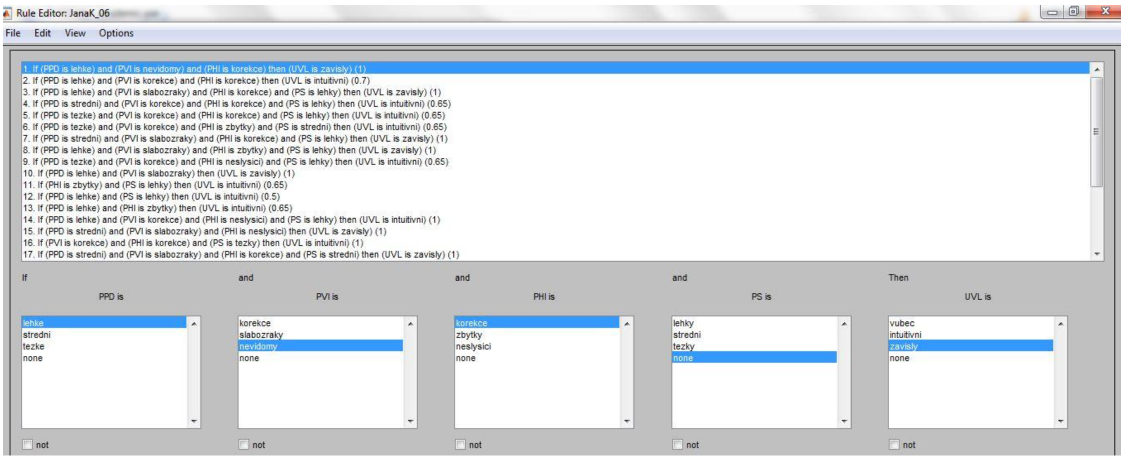
***Rule basis** as the output:*

1. *If (PD is mild) and (VP is blind) and (HP is correction) then (UVL is fully used) (1)*
2. *If (PD is moderate) and (VP is correction) and (HP is correction) and (MP is mild) then (UVL is partly) (0.35)*
3. *If (PD is severe) and (VP is correction) and (HP is correction) and (MP is mild) then (UVL is partly) (0.75)*
4. *If (PD is moderate) and (VP is low) and (HP is non)and (MP is medium)then (UVL is used)(1)*
5. *If (PD is mild) and (VP is correction) and (HP is deaf)(MP is mild) then (UVL is used) (1)*

   ....

25. *If (PD is non) and (VP is correction) and (HP is correction) and (MP is non)then (UVL is unused)(0.25)*

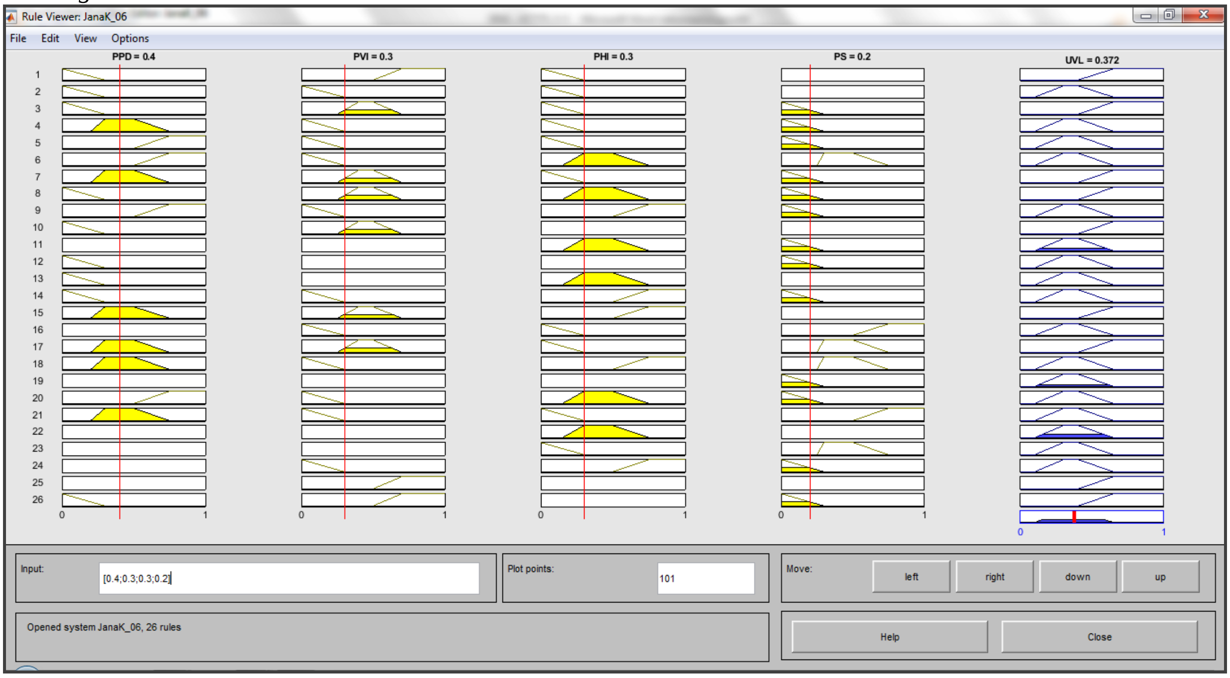
Fig. 8.
Rule basis as the output



Source: Rule Editor

The most frequently used method of the Center of Area was used for defuzzification, when a sharp value is determined by the coordinates of the area of the unified output fuzzy sets (Jura, 2003). *Rule Viewer* is a control tool in the Fuzzy Logic Toolbox; it shows all inferential rules applied in the model. The result is visible in the graphic part and it is simultaneously displayed numerically at the output variable. See Fig. 9. On the basis of combinations of specific limitations, the authors of the text modelled eight real persons, and the result of the set determines the usability of a tactile indicator in a smaller space.

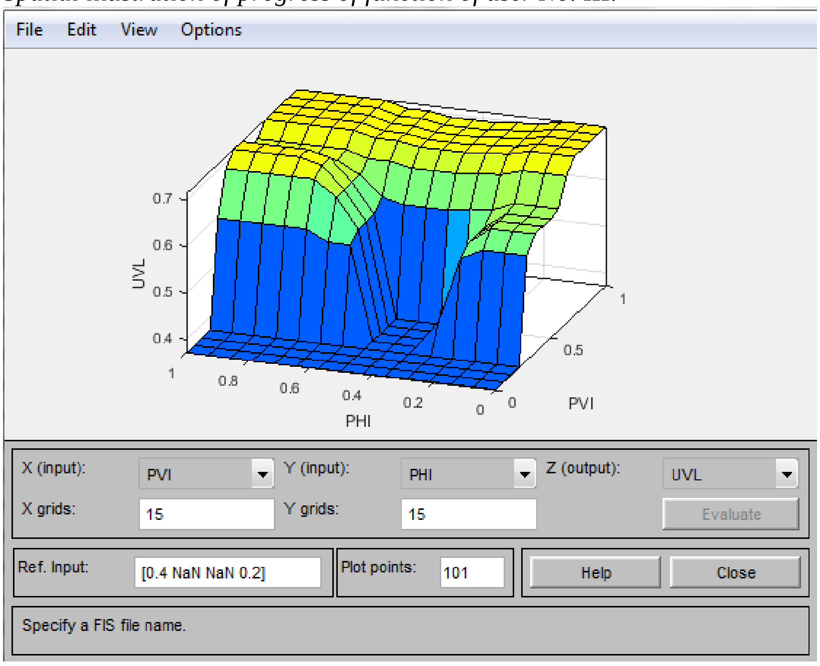
Fig. 9.
Passenger No. I



Source: Rule Viewer

Surface Viewer is the second control tool in the Fuzzy Logic Toolbox. The illustrated surface shows the progress of two chosen input variables from the X axis and Y axis on one output variable Z axis. The user No. III defined by $\langle 0,4|0,3|0,3|0,2 \rangle$ is illustrated in the Fig. 10. More specifically, a person aged 62 is concerned. This person uses one walking stick and a hearing aid in one ear. Due to Diabetes of the 2^{nd} type, the person suffers from the beginning diabetic retinopathy, which is still only a very mildly limiting factor in his / her spatial orientation but does not cause any serious problems. The result brought by the calculation points to such a reality in which the tactile indicator in the given space will be perceived intuitively, and the person is likely not to use it. See Tab. 6.

Fig. 10.
Spatial illustration of progress of function of user No. III.



Source: Surface Viewer

3. Conclusion

The model outputs and the research results point to the usability of tactile elements (TWSIs) in waiting rooms and departure halls of the ground plan dimension up to 8 × 8m. See Table 6.

Table 6
Evaluation of the TWSI usability related to specified persons

Evaluation of usability of tactile indicators related to the specified types of persons					
User	**PD / mobility**	**VD / vision**	**HD / hearing**	**MD / orientation**	**Use of TWSI**
I.	0,2	0,2	0,3	0,7	**0,37**
II.	0,2	0,2	0,3	0,7	**0,37**
III.	**0,4**	**0,3**	**0,3**	**0,2**	**0,37**
IV.	0,7	0,3	0,5	0,4	**0,37**
V.	0,9	0,3	0,2	0,3	**0,37**
VI.	0,3	0,5	0,1	0,3	**0,61**
VII.	0,3	0,7	0,1	0,3	**0,65**
VIII.	0,1	0,9	0,3	0,3	**0,66**

Source: Rule Viewer

The mathematical model created with the support by the Fuzzy Logic Toolbox confirmed our assumption – in case of all users (except for blind persons or persons with low vision) the usability will be in the medium area of intuitive utilization. That means that neither “rather yes” nor “rather no” can be used as the resulting evaluation. The worse the vision comfort, resp. light conditions in the given space is, the more important the usability will be. However, the research results have revealed that this can be claimed dominantly for spaces in which one of the dimensions excesses the length of 8 m.

Every user´s independent and safe mobility inside a transport facility should be ensured by the following:

- access to the main entrance from a public transport stop (or a wheelchair access),
- the shortest possible route between the entrance and the information office or the ticket office (a possibility of assistance service),
- a route to public toilets and vertical link (elevator, staircase, escalator),
- a route to platforms (access to departures) – see Tomandl et al. (2017).

Availability of TWSIs is of a great help for the visually impaired because thanks to it they can walk independently and safely. However, like in case of every safety element, their usability must be ensured for all user groups (passengers). TWSIs must not create barriers for the others and they must be safe and functional (distinguishable) during all the existence of the facility. (Mizuno et al., 2008) Inside transport facilities where the length without a guiding line in the walk direction does not exceed the distance of 8 metres (in waiting rooms and departure halls), acoustic guiding beacons with a voice phrase should be preferably designed (Guideline SŽDC No. 118, 2017).

The data processing which was carried out within the framework of the aforementioned research applying the Fuzzy system confirmed that tactile elements installed additionally in a small space in which the guiding line is not interrupted are a kind of redundant information. These elements will not be perceived by other users except for severely visually impaired persons for whom a correctly installed acoustic guiding beacon is a more convenient item of information about the space. In a guidance and information system, an (AOM)[7] acoustic guiding beacon with a voice phrase installed over the entrance door is a safety element for everybody. Excessive designing of tactile indicators causes an irreversible degradation of historic surfaces (not only in case of buildings within the system of cultural heritage preservation) and, simultaneously, it is an unnecessary barrier for persons with limited mobility.

[7]AOM: acouistic orientation or guiding beacon

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