International Journal of Engineering & Technology, 7 (4.8) (2018) 824-830

International Journal of Engineering & Technology

Website:www.sciencepubco.com/index.php/IJET

Research paper

Integrated Assessment Level of Service Street and Road Environment to the Needs of Persons with Disabilities

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Abstract

The work defines the assessment criteria and formation of street and road environment to the needs of people with limited mobility for solution the fundamental principles for while addressing architectural and planning issues and theoretical foundations of long-term planning for urban mobility. Characteristics accessibility tools and the calculation method of certain parameters: density pedestrian flow; the width of the roadway; the time required to overcome the roadway people with disabilities; relative grip factor of wheels wheelchair road are specified.
Suggested methods of comprehensive evaluation of street and road maintenance environment to the needs of people with limited mobility and the suggestions of streets and roads network and its elements improvement are elaborated.

Keywords: *accessibility; assessment criteria of streets and urban roads; comfort; comprehensive evaluation of the service order level; informative; people with limited mobility; safety*

1. Introduction

The modern environment is densely built-up. But it is extremely important that it is adapted to meet the needs of all people alike.
Progress in science and technology, the intensive development of medicine and pharmacology, the improvement of quality and global life expectancy have resulted in increased involvement of people with limited mobility, including: people with disabilities, elderly, children, etc.
In developed countries, people with limited mobility adaption to social in-infrastructure, and especially people with different nosologies disability have been pursued.
People with disabilities abroad have equal rights with healthy members of society and do not experience problems with communication, learning, employment and mobility in the environment.
For barrier-free and comfortable movement creating on the settlement territory different means are aimed.
The challenge with people limited opportunities needs and their right to a comfortable life and sustained work ensuring is appearing. The country faced problem of having an insufficient number of technical information to establish a barrier-free street and urban road space for people with different nosologies of invalidity.
Numerous researches in this study show that for design street and urban road environment (SRE) it is necessary to define the fundamental principles taking into account the needs of people with limited mobility (PLM).

2. Defining the Problem

The analysis of the structure of the population of advanced countries and Ukraine showed growth trends group of people with disabilities (up 32%) (Fig.1).



Fig. 1: Analysis of the number of people with disabilities in European countries

Because this group is quite significant, it includes people with different special needs, and it has been structured and classified. Based on the research 7 subgroups of people with disabilities were highlighted: people who move with their own wheelchair or with other persons help; people with walking disabilities (on crutches, on prostheses, people with violation of the musculoskeletal system, etc.); people with view disabilities; people with hearing disabili-

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ties; people with mental disabilities; people who move with attendant or seeing-eyed dog; other people who are temporarily within the definition of limited mobility PLM (pregnant women, children, the elderly, etc.).

The experiences of streets and urban roads designing to the needs of people with limited mobility in the advanced countries have been analysed. The experience in planning, construction and reconstruction of streets and urban roads of cities Ukraine and trends in the formation barrier-free area have been studied and systematized. The requirements for streets and urban roads network to meet the needs of all people with disabilities have been studied and classified.

The analysis of the modern national regulatory base, the regulatory requirements of the CIS and the United Nations has shown that:

1) the technical information on the design of SRE elements for users with limited mobility in Ukraine is represented in various regulations fragmented and incomplete, and in some cases – with different values;

2) in the typical cross-sections of streets and roads of Ukraine settlements there are no elements of the barrier-free streets and urban roads network (there are no lanes for the movement of people on specialized devices (hand operated bikes, electric vehicle);

3) in Ukrainian regulatory requirements there are no readily available data about the calculation methods of the separate parameters of the streets and urban roads network: the required sidewalks width, the required time for crossing the roadway, the density of the pedestrian traffic, the coefficient of adhesion of the wheelchair with the pavement;

4) there is no methods for determining the quality of servicing te SRE to the needs of people with limited mobility. The modern tendencies and features of designing and reconstruction of the SRE of the settlement were considered.

Nowadays, in advanced countries, reprioritization among road users is being introduced. Now it's a pedestrian and a people with limited mobility. So, as we can see, Ukraine, like other countries, was brought before the problem of adapting urban construction and reconstruction projects of city streets to change the priorities that occurred in the theory of transport planning (Fig. 2 [4*]). The task of ensuring this priority arises through the development of regulatory requirements, reconstruction of the SRE and implementation of various measures.

3. Defining the criteria of street and urban road accessibility

As a part of streets and urban roads environment research for the purpose of adapting it to the needs of people with limited mobility, an experiment "Survey of the existing state streets and urban roads environment in Poltava and other settlements of Ukraine regarding the conditions of accessibility for people with disabilities" was conducted. The generic routes of Poltava have been studied and graded. There are routes to: medical and health facilities, administrative buildings; commercial and household facilities; higher education institutions; recreational zones; enterprises where people with disabilities work; schools and kindergartens where children with disabilities study.

Since then, the most widespread routes used the people with limited mobility were identified by interviewing and cooperating with various organizations of people with disabilities. The experiment consisted in the allocation of the most vulnerable 3 subgroups of people with disabilities (wheelchair users, people with visual impairment, hearing impaired people) who have traveled these routes with the timekeeping of time and effort.

Studies have shown that on some routes, a person with hearing impairment spends in 1.5 times more time than a conditionally healthy person; a person who moves on a wheelchair spends in 3-3.5 times more time; for the blind, the length of the well-known route increased in 3.5 times, and the time and effort of using unknown traffic routes increased in some cases by more than 6 times.

Some routes on the VRE territory are not accessible to the people with limited mobility. Public transport stops, underground and aboveground pedestrian crossing, transit route are inappropriate for the needs of people with limited mobility have been defined.

Criteria for barrier-free street and urban road environment are safety, accessibility, comfort, informatively, which have separate means of organizing a non-barrier space: accessibility – curbs, sidewalks, pedestrian crossings, special platforms to pick up and drop passengers, crossover track, parking places; safety – ramps, stairs; informative - tactile means (warning signs, lighting, information boards); comfort – the quality of the road pavement, lifting devices and aesthetic are determined on the basis of the analysis of native and foreign design practices, construction and using of a residential and public buildings and structures, street and urban road infrastructure, and taking into account the experience of experimental design and reconstruction of objects (Fig. 2).

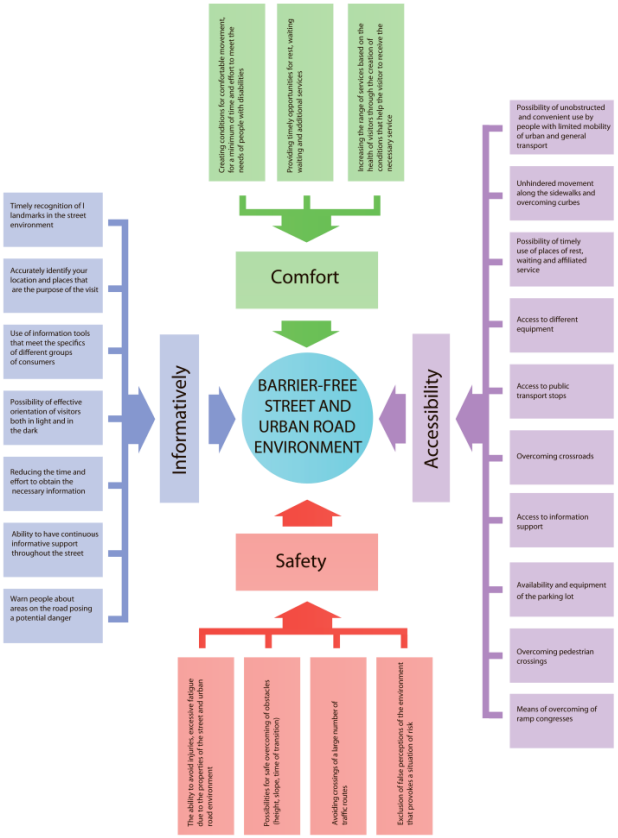


Fig. 2: Criteria for barrier-free street and urban road environment to meet the needs of all people with disabilities

In general, the following problems of using the street and urban roads environment of the people with limited mobility were identified: the non-possibility or difficulty of overcoming the high-altitude differences between the roadway and the sidewalk; difficult maneuvering in a confined space; difficult to overcome the intersection, obstacles on the sidewalks; the impossibility of free movement through a dense movement and different speeds of pedestrian flows along sidewalks and transit roadways; difficulty in identifying obstacles; lack of access to underground and overland pedestrian crossings, to public transport stops; lack of parking zones; lack of territories marking; lack of time for the movement during the passage through the pedestrian crossing; incompatibility of the pedestrian crossing width, information support, number of rest places; inconsistency of pavement quality and lack of specialized surface and equipment.

Criteria for the barrier-free street and urban road environment creation, include requirements which shown in Fig. 3–6 have been defined on the basis of the analysis of native and foreign practices in the design, construction and using of a residential and public

buildings and structures, SRE, and taking into account the experience of experimental design and reconstruction of objects with accessibility creation.

The basic principles that must be used at designing and reconstruction of SRE and their priority are suggested.
For the new classification, it is suggested to extend 4 criteria using the principles of designing SRE and determine their priority (Tab.1).

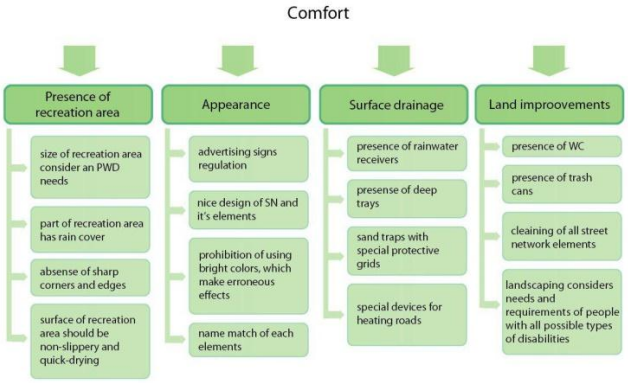


Fig. 3: Components of the comfort criteria

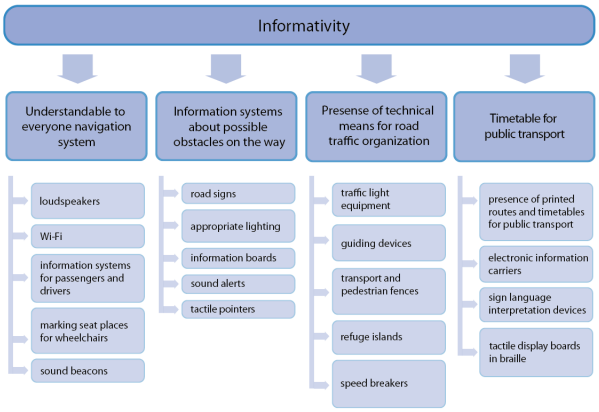


Fig. 4: Components of the inormativity criteria

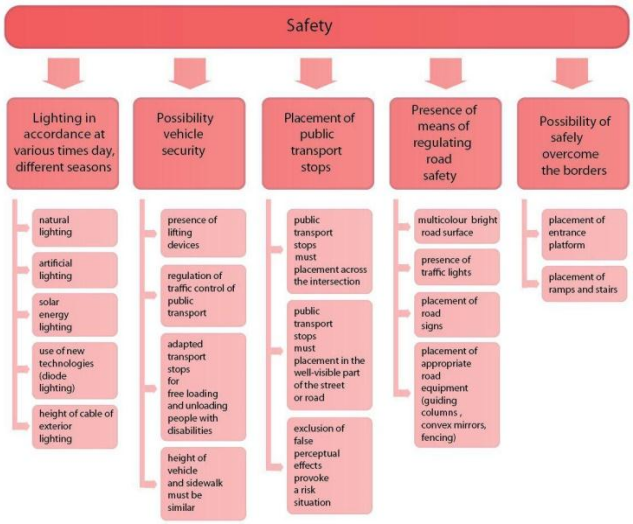


Fig. 5: Components of the safety criteria

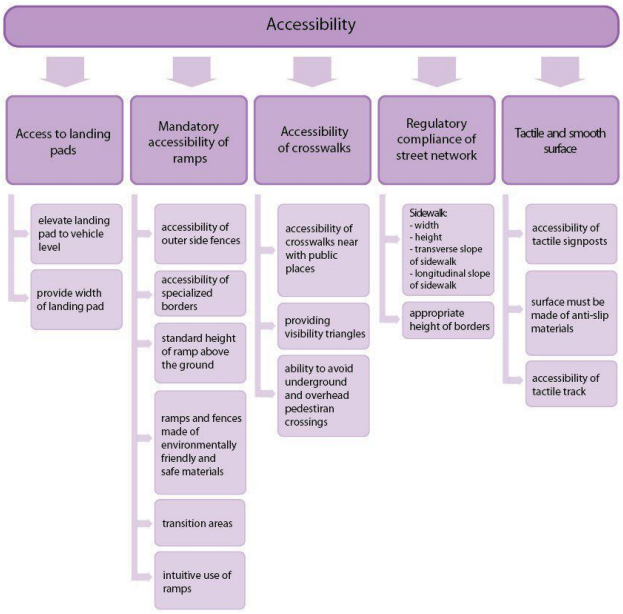


Fig. 6: Components of the availability criteria

Table 1: Priority of the principles of VDS design

Principle	Criterion	Priority
Functional integration	Accessibility	1
Functional differentiation	Accessibility	1
Compactness	Accessibility	1
Town-planning integrating	Accessibility	1
Microdistricts creation	Accessibility	2
Construction of optimal streets and urbun roads etwork	Safety	1
Functional zoning,	Accessibility	2
Non-conflictual	Safety	1
Modernization	Comfort	3
Aesthetic attractiveness	Informatively	3
Visual perception	Safety	1
Sequentialization,	Comfort	3
Design of spatial corridor	Safety	1
Universal design	Accessibility	2
«Smart adaptation»	Accessibility	3
Accessibility	Accessibility	1
Comfort	Comfort	3
Informatively	Informatively	2
Safety	Safety	1

The identified criteria and principles are proposed to be combined in a comprehensive evaluation of street and road maintenance environment to the needs of people with limited mobility.

4. Comprehensive evaluation of street and road maintenance environment to the needs of people with limited mobility

The main problems faced by limited mobility groups (LMG) of persons with disabilities when using the streets and roads of the settlement require a thorough investigation, specification of the characteristics of accessibility facilities and the development of a method for calculating certain parameters: the density of the pedestrian flow (Q_{lmg}); width of the travel section (B_{lmg}); time required to overcome the traffic of people with disabilities (V_{lmg}); Relative coefficient adherence of a wheel of a wheelchair with a road surface (k_{lmg}).
An experimental study found that the greatest problem in LMG arises when overcoming pedestrian trails. The conducted analysis showed that pedestrian traffic in the total volume of urban travel is 30 - 35%. It is characterized by: speed; distance uneven distribution of streams along the length of the street network and in time;

current density, which is determined by the number of pedestrians per 1 sq.m of area.

According to the national requirements for determining the width of the sidewalk a conventional strip of 0.75 m width is given for the estimated lane. But, as the experiment showed, this parameter does not take into account the needs of people with limited capabilities. Therefore, on the basis of the definition of the norms of the planning elements for different categories of people with disabilities, it is proposed to supplement this method [9] with the estimated parameters for people with limited capabilities.

Increasing the magnitude of the planning normal for LMG in calculating the required width of the pavement will reduce the number of conflict situations between different pedestrian streams, thereby creating favorable conditions for traffic for all the users of the street and road environment.

Improvement of the street and road environment (SRE) of the settlement, the ordering of urban passenger transport, the creation of alternative networks for the movement of environmentally friendly modes of transport, the provision of the necessary number of parking areas and storage of the means of transport determines the important directions at reconstruction, one of these directions should be of social efficiency, which aim is to improve the living conditions of the population and reduce the time for commute.

It is proposed to determine the quantitative characteristic by the help of the German - Prigogine criterion, which is based on the use of two components of the time spent, time in the motion and time during the delay. These two elements reflect the effects of various factors that affect the state of the traffic flow. Therefore, this criterion is recognized as an integral one. An important plus of this kinetic theory is the possibility of taking into account two separate states of the traffic flow [10].

At the same time, such a criterion is intended to create conditions for the movement of vehicles, while European countries give a priority to pedestrians. Therefore, on the basis of this model, a comprehensive assessment is made of the level of street and road maintenance for pedestrian traffic, taking into account the needs of limited mobility groups.

A comprehensive assessment of the level of service of the SRE, taking into account the needs of different subgroups of the LMG, is proposed, and includes the provision of criteria for safety, informativity, accessibility, comfort, taking into account the needs of limited mobility groups of people with disabilities (Figure 4), to be performed with the following tasks (Table 2).

The movement of the pedestrian flow is subjected to the influence of several factors. This determines the probable character of human behavior during movement. First of all, for the construction of the simulation model of the pedestrian flow, which takes into account the needs of the LMG, the dependence of "intensity-density-speed-"right for mistake" was taken into account (1)

$$N_{lmg} = p \times q \times V \times k_{lmg} \quad (1)$$

where p – intensity of the pedestrian flow;
q – density of pedestrian flow;
V – speed of pedestrian flow;
k_{lmg} is a coefficient that takes into account the "right to mistake".

It is assumed that the determination of the number of LMGs during and throughout the studied area depends on the intensity of the pedestrian flow at the entrance to and exit from the site. Because of this, the dependence of the change in the density of the pedestrian flow can be obtained, taking into account people with limited capabilities (2):

Table 2: Tasks of the complex assessment of the level of service SRE taking into account the needs of LMG

Task Comprehensive Assessment of Service level	Parameters SRE
1. Evaluation of the state of the street and road environment (SRE) for limited mobility groups (LMG)	1.1. Time expenditures on the motion of the SRE for LMG 1.2. Quantitative characteristics of transport and pedestrian traffic 1.3. Environmental characteristics of streets and roads of settlements 1.4. Conflict situations that arise between transport and pedestrian streams 1.5. Conflict situations that arise inside the pedestrian flow
2. Definition of unfavorable places for movement of LMG	2.1. Speed of movement on the SRE 2.2. Speed of vehicles 2.3. The proximity of transit routes to streets and roads 2.4. Traffic concentration areas due to conflict situations 2.5. Absence of alternative ways of movement
3. Determination of the most safe and accessible traffic conditions for SRE for LMG (optimal distribution of pedestrian streams, provision of priority traffic conditions).	3.1. Matrix of correspondence 3.2. LMG traffic routes at SRE 3.3. Loading of SRE by public transport, individual transport and pedestrians 3.4. Location and characteristics of public service objects 3.5. Intensity of movement of pedestrians and vehicles 3.6. Provision of parking areas

$$\Delta n_{lmg} = (N(x) - N(x+\Delta x) \times \Delta t \times k_{lmg} \quad (2)$$

where Δn – the magnitude of the change in the number of people in the traffic area, number of people.;
$N(x)$ – the intensity of the pedestrian flow, at the entrance to the explored area, person / m;
$N(x+\Delta x)$ – the intensity of the pedestrian flow, which crosses the pedestrian crossing per person per hour;
Δx – is the length of the approach to the intersection which is being investigated;
Δt – period of time for which the change in the density of the pedestrian flow, h.

The application of the proposed model makes it possible to analyze the shock wave parameters in the pedestrian flow.

The next step in estimating and modeling the pedestrian flow in the approach to the regulated intersection is the use of elements of the theory of micromodulation, when each person with disabilities is a separate object [11].

For the construction of the simulation model, the basic assumptions are taken - depending on the conditions of the LMG movement, certain types of behavior are defined: acceleration, inhibition, expectation, observation. The developed model allows to reflect the process of flow of a different density. At the first stage of the model's work, pedestrians are generated at the beginning of the selected section of the SRE (with the coordinate $x = 0$), which is removed from the simulation process after reaching the coordinate $x = 1000$ by the person. The behavior of each pedestrian with a disability determines the current acceleration, which responds with a given step.

In the process of simulation, an impulse is generated that reflects the traffic signal forbidding a person with a disability (the distance from the coordinate of his location is less than his braking time). When approaching the next pedestrian at a distance equal to the braking distance, the object also begins to slow down. Thus, the process of compaction of the pedestrian flow in the direction of its movement is created. Consequently, the model allows to trace and analyze the "shock wave" of the pedestrian flow, which tracks LMG.

Output parameters of the model are:

– maximum speed LMG V_{max} (set by the user) by default 7-8 km/h;

– maximum acceleration at acceleration, a_{1max}, by default 0,25 m/s (set by user);

– maximum deceleration during braking, a_{2max}, by default 0,01 m/s^2 (given by the user);

– the duration of the prohibiting signal, t_3 (given by the user), by default for 60 seconds;
intensity of the pedestrian flow, *N*, by default 500 people/hour;
– maximum pedestrian flow density
– maximum pedestrian flow density, q_{max} (set by the user), by default, 2.25 m/person.
The value of accelerating pedestrians is not taken into account at each stage of the assessment of the quality of the SRE. It should be noted that in the process of modeling there is a situation where pedestrians in a dense stream continue to move at a critically low speed (0.01 km / h and below). A number of empirical studies have suggested that the movement of pedestrians with such speeds may occur. Thus, in a dense flow there is an effect of hysteresis loop, when there is a certain "delay" of the reaction of the object to the change of the external environment (in the task of dynamic control of pedestrian flow - the external environment can be considered the state of the flow, namely, its density). Using the hysteresis loop allows to take into account the behavior of the person with disabilities, namely - the reaction on changing the distance between pedestrians in a dense stream.
Thus, the status of each pedestrian with a disability in the flow can be described as a matrix

$$A = \begin{bmatrix} x_1 & x_2 & x_3 & \dots & x_n \\ \dot{x}_1 & \dot{x}_2 & \dot{x}_3 & \dots & \dot{x}_n \\ \ddot{x}_1 & \ddot{x}_2 & \ddot{x}_3 & \dots & \ddot{x}_n \\ j_1 & j_2 & j_3 & \dots & j_n \end{bmatrix} \quad (3)$$

where x_i – the current coordinate of the movement of the pedestrian in the stream;
n – the number of people who are in a certain area, one;
$\dot{x}$ – acceleration of a person with disabilities;
$\ddot{x}$ – speed of a person, km / h;
j – time counter of the traffic light object.

At each stage of the integration of this model, the following actions are performed:
1. A subprogram for determining the traffic-light control is called.
2. At the beginning of the plot, a person with disabilities is randomly generated.
3. The presence of obstacles for the generated pedestrian is determined, as well as the distance to him if it is available.
4. The required speed for safe movement at a distance to the nearest obstacle is determined (Fig. 7).

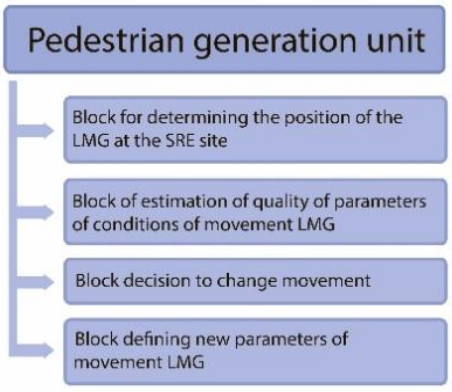


Fig. 7: Block diagram of the calculation algorithm model for pedestrian flow, which takes into account the needs of LMG

As a result of the simulation, it was determined that the proposed method of dynamic control without determining the parameters of management (distance, speed) does not allow us to eliminate completely the queues that may arise when the person approaches to the pedestrian crossing.

In order to improve the traffic conditions for LMG, it is proposed to apply a comprehensive assessment of the street-road environment service level.
On the basis of the fact that the definition of the effectiveness of the operation of SRE is carried out according to social, environmental, economic, safe, comfortable, accessible, informative criteria, the most important indicators of their assessment are identified. SRE consists of separate routes, which includes a certain set of network elements that provide a link between the separate forming and absorbing parts of the settlement.
The definition of common indicators begins with the definition of the matrix of observation followed by the structuring procedure. First determine the elements of the matrix of observation X.

$$X = \begin{bmatrix} x_{11} & x_{12} & x_{1k} & x_{1n} \\ x_{21} & x_{22} & x_{2k} & x_{2n} \\ x_{i1} & x_{i2} & x_{ik} & x_{in} \\ x_{t1} & x_{t2} & x_{tk} & x_{tn} \end{bmatrix} \quad (4)$$

where *n* – number of private indicators;
t – number of items for which partial figures are calculated;
x_{ik} – value of the partial index k for element i.

The observation matrix is compiled separately for intersections, obstacles, and intersections occurring during LMG movement. The elements are the relevant criteria: safety, availability, informativeness and comfort.
The obtained data is proposed to combine in the Comprehensive Assessment of the Level of Service (CALS) of investigated routes of traffic for LMG. The analysis of integrated indicators suggests that today, when solving the problems of organization of pedestrian movement, indicators are used, which are developed on the basis of "expert estimation method". The main limitation of this method is the possible subjectivity of the results obtained. This shortcoming is proposed to be excluded using the criterion of Hermann-Prigogine.
The criterion of Hermann-Prigogine (5) is based on the use of two components of the specific time expenditures - time spent in motion and time during the delay [12]. These two elements reflect the effect of various factors that affect the state of the traffic flow, so this criterion is considered integral. An important plus of this kinetic theory is the possibility of taking into account two separate states as well as the pedestrian flow. This criterion is intended to create conditions for the movement of transport vehicles, while European countries prioritize pedestrian movement. Therefore, on the basis of this model, a comprehensive assessment of the level of servicing of the street and road environment is proposed, taking into account the needs of the limited mobile groups of physically challenged people of the population.

$$T_s = T - T_m^{\frac{1}{1+n}} \times T^{\frac{1}{n+1}} \quad (5)$$

where T_s – stopping time, s;
T_m – this is the average travel time per unit distance, s;
n - road traffic quality indicator.

In order for this formula to take into account the needs of the LMG, it is proposed to introduce a coefficient of Klmg, which will reflect the application of the principles of the organization of barrier free street-road environment. After entering the coefficient, this form will be as follows:

$$T_s = \left(T - T_m^{\frac{1}{1+n}} \times T^{\frac{1}{n+1}} \right) \times k_{lmg} \quad (6)$$

where k_{lmg} – a coefficient that takes into account the needs of the LMG during the movement at the SRE (Fig. 8).

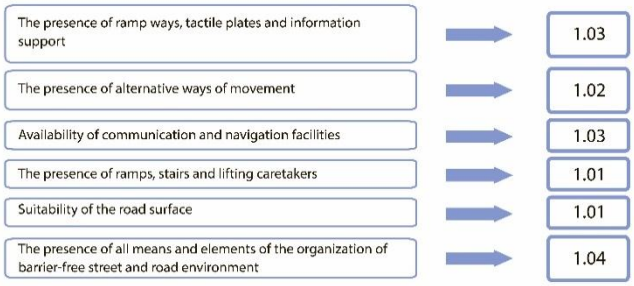


Fig. 8: The value of the k_{lmg}, coefficient, which takes into account the needs of LMG

The general regularity of the functioning of the SRE for LMG can be conditionally estimated by the efficient operation of the transit routes. In the process of choosing a route, a physically challenged person tries to realize the benefits that are personally subjective and not always effective from the standpoint of the system as a whole.

For the compilation of the matrix of observation, the routes of the experimental study were used. It is composed separately for the intersection, obstacles and intersections that occur during the movement of LMG. The elements are the relevant criteria: cross-section indicators, speed of the traffic flow, the presence of ramps or ramp congresses, etc.

The obtained data is proposed to be combined into a comprehensive assessment of the level of service of the studied routes of traffic for LMG (Fig. 9).

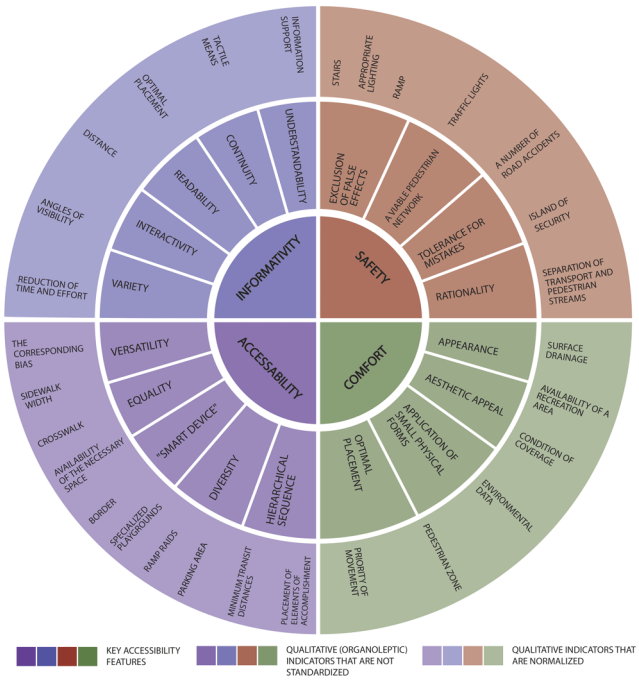


Fig. 9: Criteria for a comprehensive assessment of the level of maintenance of street and road environment, taking into account the needs of limited mobility population groups

The quality of the indicators of the functioning of the street and road environment, taking into account the needs of limited mobility population groups, is proposed to be determined by a comprehensive assessment of the level of service, which is as follows: the integrated indicator of estimating the effectiveness of the route is the area of the traceable area of motion (k_{lmg}), which we asses as:

$$k_{lmg} = \frac{L_p}{T_s}\gamma_n \quad (7)$$

where L_p –the total area of the area we are exploring;

T_s – the value of time needed in accordance with the criterion of Hermann - Prigogine;

γ_n – a coefficient that takes into account the presence of erroneous effects of the surrounding space.

The coefficient, which takes into account the needs of the LMG and the presence of false effects, is determined by the radar principle - all the monitored indicators have the same weight, so the circle is divided by the radial scales at the sector level, the number of which is equal to the number of estimating parameters.

$$\gamma_n = \frac{360^o}{n} \quad (8)$$

where n – number of indicators.

The use of this technique gives an opportunity with a high degree of reliability and a minimal influence of the possibility of subjectivity of opinions to obtain a comprehensive assessment of the quality of service level of the SRE for LMG.

5. Conclusions

Consequently, the performed analysis of the structure of the population of the developed countries of the world and Ukraine revealed the tendencies of the growth of the limited mobility group of physically challenged people (up to 32%). The major laws of Ukraine and the UNO are considered in order to take into account the needs of limited mobility users. The necessity of creating a non-barrier space is grounded in order to provide the ability to navigate for LMG, creating space for their adaptation.

A comparative analysis of the modern regulatory framework for the creation of a barrier-free street environment taking into consideration the needs of all people with disabilities and other people showed that the technical information on the design of elements of the road network in Ukraine is presented in various regulatory documents fragmentarily and not in full scale and there is no single regulative document. In the regulatory documents of Ukraine, laying tracks for the passageways for people with disability is assumed only where there is a necessary number of pedestrians; in the typical cross-sectional profiles of streets and roads of settlements there is no distinguished strip for LMG, also ; there is not enough data on the methods of calculating the required pedestrian flow density, not always there is an adequate time parameter for crossing the traffic area by LMG and also it is need to clarify the value of the minimum permissible width of the pavement.

The complex estimation of the level of servicing of the street-road environment (SRE) is proposed, which allows to estimate the needs of limited mobility groups of the population. The use of this technique will allow a comprehensive assessment of the level of service of the SRE for LMG with high degree of credibility and a minimal impact of subjectivity.

Acknowledgement

The work is related to the research work of the department of automobile roads, geodesy, land management and rural buildings of Poltava National Technical Yuri Kondratyuk University (Ukraine) - "Improvement of highways and street-road network" (Project ID: 0114U000354).

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