Quantitative assessment of infrastructure facilities availability in biosphere-compatible city functions implementation

N V Bakaeva¹, I V Chernyaeva²

¹Department of industrial and civil engineering, Southwest State University, 94, 50 Let Oktyabrya Street, Kursk 305040, Russia
²Department of municipal economy and road construction, Orel State University, 95, Komsomolskaya Street, Orel 302026, Russia

E-mail: schunya87@yandex.ru

Abstract. The concept of infrastructure facilities availability for population within the implementation of biosphere-compatible city functions is defined. The classification of city functions availability on the basis of territorial, time-dependent and individual characteristics is presented. The algorithm for the assessment of infrastructure facilities availability by means of comparing actual and specified indices is provided in the article. The quantitative implementation of the developed method using the example of one of the residential areas of the city of Orel is provided. The proposed method for the assessment of infrastructure facilities availability enables analyzing the state of the area and the viability of urban development solutions and feasibility of area redevelopment. The quantitative distribution of the integrated index of availability of infrastructure facilities and further assessment of the implementability of functions of a biosphere-compatible city enables studying urban development design solutions and innovation of urban development encouraging proper human development and increasing human potential.

1. Introduction
Cities as a place of concentration of the mainstream of population, are historically designed to provide their residents with a high, environmentally friendly quality of life. Being a developed economic complex and a cultural center, cities are the centers of major environmental problems [1-6]. In the conditions of the unfavorable ecological situation in many cities of Russia, the creation of urban policy in the field of urban infrastructure planning, design and construction of residential areas should be carried out on a qualitatively new basis.

According to many scientists, it is the greening of the urban environment as a global trend of development (for example, in Russia 2017 is declared the year of ecology) that is currently a vital need of mankind. This is shown by the European environmental directives of different years, the Climate Change Conference in Paris (2015), the Copenhagen Accord (2009), the Kyoto Protocol (1997) and other documents. The Russian Academy of Architecture and Construction Sciences (RAACS) developed the paradigm of biosphere compatibility (the concept of biosphere compatibility of regions, cities and settlements) supported by interdisciplinary scientific research, aimed at ensuring safety and comfort of engineering, social and natural-technogenic systems of settlements [1-8 et al.]. One of the principles of this concept is the principle of meeting the reasonable needs of population through the
city functions: essential services, entertainment and recreation, governance, charity, knowledge, creativity and connection with nature [3-4].

Quantitative assessment of city functions is of great importance for the solution of urban development problems as it makes it possible to make them measurable, i.e. knowing needs of people from different social groups and the time required for their satisfaction it is possible to assess the availability and implementability (completeness) of the existing services. For instance, how much time a person can spend in a theatre or a museum if all the citizens would like to visit it. Scientifically, to solve the problems of area planning, urban development zoning, urban planning and redevelopment, a hypothesis of equal significance of territorial, time-dependent and personal availability of city functions to a person related to his rational needs and providing safe and comfortable living conditions is developed. It would make sense to provide annual assessment, specify the time of implementation of each function for a person on the basis of statistic data for developed cities depending on the place of residence, climate, living conditions, ethnic considerations and other factors [1-5].

In terms of availability of urban infrastructure facilities, we can assess time provided for every citizen to satisfy their needs. Naturally, the required time depends on the population age, social affiliation, employment, and needs. Statistically, it can be measured, then the obtained data are compared with the data obtained either in different cities, or within one city during a long period of time. Therefore, optimum indices in terms of human development can be determined, and correspondingly, certain changes can be made in the city structure. Then, index “time, provided for a person for his reasonable needs satisfaction” can be laid as an index of settlement plot plan by means of architectural and civil engineering.

2. Results and discussions

Concept “availability” is interpreted in different ways. In respect to urban infrastructure facilities three approaches can be distinguished:

- in terms of the convenience of location (territorial availability);
- in terms of accessibility regarding time (time-dependent accessibility);
- in terms of their availability for certain groups of population, including cost of services (personal accessibility and affordability).

Location factor of urban infrastructure facilities is becoming critical for the creation of comfortable and safe living environment and is fundamental to determine territorial availability.

In terms of biosphere compatibility, it is proposed to use as a criterion of territorial availability of urban infrastructure facilities \( \alpha_{ter} \), a radius of the area of services of institutes and enterprises located in the residential buildings zone within one residential area. To determine the index of availability it is necessary to compare the actual population service-area radius value and the specified ones (Table 1).

| Comparison of actual \( \alpha_{ter}^a \) and specified \( \alpha_{ter}^n \) values | Territorial availability index assigned by experts |
|---------------------------------------------------------------|--------------------------------------------------|
| \( \alpha_{ter}^a \leq 0.5 \alpha_{ter}^n \) | 1 |
| \( 0.5 \alpha_{ter}^n < \alpha_{ter}^a \leq \alpha_{ter}^n \) | 0.5 |
| \( \alpha_{ter}^a > \alpha_{ter}^n \) | 0 |

Note: \( \alpha_{ter}^a \) is the actual population service-area radius, i.e. the actual shortest distance to the facility; \( \alpha_{ter}^n \) is the radius of the area of institutes and enterprises service areas located in residential area in accordance with the regulatory codes (SP 42.13330.2011. Urban development. Planning and development of urban and rural settlements).

Territorial availability index should consider remoteness of the facility from the required facility, proximity of the facility to traffic arteries, underground stations, and surface transport stops in accordance with regulatory design documentation. Therefore, the concept of territorial availability
incudes transport availability [9-13]. So, if it is necessary to determine the index of territorial availability within a city or town, it is necessary to take into account public transport availability [9-13] (Table 2) and proximity of the facility to the underground stations and surface transport stops (Table 3).

### Table 2. Values of the index of public transport availability \( d_{tr} \).

| Parameter under study | \( d_{tr} \) index value assigned by experts |
|-----------------------|--------------------------------------------|
| Number of types of public transport going to the facility: | |
| 0                    | 0                                          |
| 1-2                  | 0.5                                        |
| 4 and more           | 1                                          |
| Time spent in public transport: | |
| \( t^a > t^p \)      | 0                                          |
| \( 0.5 t^a < t^p \leq t^p \) | 0.5                                        |
| \( t^p \leq 0.5 t^a \) | 1                                          |

*Note: \( t^a \) is the actual time spent by a passenger using public transport travelling to the facility; \( t^p \) is the specified (optimum or reasonable) time, required for travelling from the place of residence to the facility.*

### Table 3. Comparison of actual and specified values of \( m_s^a \) and \( m_s^n \).

| Comparison of actual \( m_s^a \) and specified \( m_s^n \) | \( m_s \) index values assigned by experts |
|----------------------------------------------------------|--------------------------------------------|
| \( m_s^a \leq 0.5 m_s^n \)                              | 1                                          |
| \( 0.5 m_s^n < m_s^a \leq m_s^n \)                     | 0.5                                        |
| \( m_s^a > m_s^n \)                                     | 0                                          |

*Note: \( m_s^a \) is the actual walking distance between the facility and the nearest public transport stops (or underground station); \( m_s^n \) is the specified walking distance between the facility and the nearest public transport stops (or underground stations).*

The index of territorial availability within a city considering public transport if it is impossible to get to the destination on foot, it calculated as follows:

\[
\alpha_{tr} = \frac{d_{tr} + m_s}{2} \tag{1}
\]

If a person drives to the destination, then the index of territorial availability depends on the following factors:

\[
\alpha_{tr} = f \left( K_R, I_{vd}, T \right) \tag{2}
\]

where \( K_R \) is the quality of roads; \( I_{vd} \) is the vehicle density; \( T \) is the driving time.

Sometimes there arises a need to compare time spent on travelling between the two destinations. In this case it is possible to assess the territorial availability and time-dependent accessibility, that depends on the total time spent to cover a distance between the two destinations. (Table 4).

### Table 4. Values of territorial availability and time-dependent accessibility \( \alpha_{tr+t} \).

| Total time required to cover the distance between the two destinations | \( \alpha_{tr+t} \) assigned by experts |
|---------------------------------------------------------------------|--------------------------------------|
| In urban area:                                                      |                                      |
| \( T^* > T^n \)                                                     | 0                                    |
| \( 0.5 T^* < T^n \leq T^n \)                                       | 0.5                                  |
| \( T^n \leq 0.5 T^* \)                                              | 1                                    |
| Within one transportation district:                                  |                                      |
| \( T^* > 5 \) min                                                   | 0                                    |
| \( T^n \leq 5 \) min                                                | 1                                    |

*Note: \( T^* \) is the actual time required to cover the distance between the two destinations; \( T^n \) is the specified (optimum or reasonable) time required to cover the distance between the two destinations.*
Time-dependent accessibility index $\alpha_t$ is determined considering the access time (Table 5).

| Facility’s working hours | $\alpha_t$ index value assigned by experts |
|--------------------------|------------------------------------------|
| Not available (closed temporarily or constantly) | 0 |
| 1-4 hours a day | 0.3 |
| 5-9 hours a day | 0.5 |
| 10 and more hours a day | 0.8 |
| 24 hours | 1 |

The index of personal accessibility and affordability is determined by the social level of living which can be defined as a complex social and economic category, reflecting the level of satisfaction of population needs for wealth and non-material services, and conditions for development and satisfaction of these needs within the city functions. Broadly speaking the concept of “social standard of living” includes conditions of work and employment, everyday life, leisure, education, health status, natural habitat, etc. In this case the terms “quality of life” or “way of life” are used. Quantitatively, the index of personal accessibility and affordability of the facility for population can be determined by means of evaluation categories of safety of travel routes and the places of residence, places of service, place of employment, human development index, effective demand for services, and average monthly income as a weighted average on the proportion of distribution by household income [14,15].

Table 6 presents comparison of actual index values of the availability of the facility in terms of the cost of the provided services with most reasonable (optimum) values.
Table 7. Availability index of the facilities in terms of service costs

| Comparison of actual $\alpha_c^{Ia}$ and reasonable values | $\alpha_c^I$ index value assigned by experts |
|-----------------------------------------------------------|--------------------------------------------|
| $\alpha_c^{Ia} \leq 3.5\%$                                | 1                                          |
| $3.5\% < \alpha_c^{Ia} \leq 10\%$                       | 0.5                                        |
| $\alpha_c^{Ia} > 10\%$                                   | 0                                          |

| Comparison of actual $\alpha_c^{Sa}$ and reasonable value | $\alpha_c^S$ index value |
|------------------------------------------------------------|--------------------------|
| $\alpha_c^{Sa} \leq 80\%$                                 | 1                        |
| $80\% < \alpha_c^{Sa} \leq 100\%$                        | 0.5                      |
| $\alpha_c^{Sa} > 100\%$                                  | 0                        |

Therefore, the index of the availability of the facility in terms of services cost is determined according to the following formula:

$$\alpha_c = \frac{\alpha_c^I + \alpha_c^S}{2}$$  \hspace{1cm} (3)

For comparative analysis of the availability of urban infrastructure facilities, a generalized Harrington’s desirability function in the form of the absolute number [19, 20], which is the quantitative index of the quality of the facility under study, can be used.

The integrated index of the availability of urban infrastructure facilities taking into account its territorial, territorial and time-dependent, time-dependent and personal constituent, will take the following form:

$$\alpha = (k_1 \cdot \alpha_{w_1} \cdot k_2 \cdot \alpha_{w_2} \cdot k_3 \cdot \alpha_{w_3} \cdot k_4 \cdot \alpha_4)^{1/4}$$  \hspace{1cm} (4)

The values of the availability indices should comply with the accepted urban development and ecological codes and social standards of the quality of life, defining the possibility to provide safe and comfortable living environment in implementation of biosphere-compatible city functions as criterion values.

**Calculation example.** Let us provide numerical implementation of the method for determination of indices of public availability of infrastructure facilities using the example of one of the residential areas in a city in the RF Central Federal District and find territorial, territorial and time-dependent, time-dependent and personal availability of its facilities for the public.

Zarechensky residential area is the biggest and a fast-developing area in Orel city. The size of the plots intended to the construction of blocks of flats and amenity infrastructure facilities is more than 200 Ha (Figure 1). By now, forty blocks of flats with a total area of 280 thousand $m^2$ have been put into service. To provide population with affordable services, social and cultural facilities are provided.

![Figure 1. 3D-plan of Zarechensky residential area.](image-url)
Nowadays, an ice rink, a nursery school for 230 children and a general education school for 550 students have been built. Another nursery school for 230 children is being built. Beside the developed school building, three more general education schools for 1728, 1296 and 844 children are designed. Four more nursery schools for 230 children each are foreseen. A municipal polyclinic for 750 visits a day is foreseen to provide medical services for the population. There is a shopping centre “Evropa” and a lot of shopping facilities and food courts in the area.

The residential area is divided into streets and block. These blocks are called: Alpijskaya polyana, Almaznye Doliny, Krylya Federatsii, Izumrudnaya Polyana, Tihaya roshcha and Altair. The subjects of the research are the school, the nursery school, the ice rink, the shopping centre, the branch of the pediatric polyclinic (Figure 2).

The integrated index of availability of city infrastructure facilities for population is found according to formula (4) considering the specified constituents: territorial, territorial and time-dependent, time-dependent and personal availability of the facilities.

The diagram of the quantitative distribution of the integrated index of availability of the city infrastructure facilities for population, obtained for the residential blocks of Zarechensky in Orel is presented in Figure 3.
It is not difficult to see that the level of facilities availability for the selected residential area (a nursery school was chosen as a research subject) is not high. This problem is a systemic one. In many Russian cities there have appeared a lot of residential areas whose main characteristics is the number of square metres of housing in the developed area even at the expense of social infrastructure facilities and codes violation.

3. Conclusion

The proposed method for the assessment of the public availability and accessibility of infrastructure facilities enables analysis of the condition of the area and assessment of the viability of urban development design concepts and groundings for the redevelopment of the existing areas. In particular, the index of infrastructure facilities availability can be considered as a plot plan index. The obtained results highlight the necessity and feasibility of further development of scientifically based guidelines to provide safe and comfortable human living environment when planning new urban residential areas and developing existing ones, on the basis of the principle of implementation of biosphere-compatible city functions to meet human needs in the best possible way.

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