Algorithm for assessing the comfort level of life support facilities and socially significant facilities by accessibility indicators

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Abstract. The concept of availability infrastructure facilities 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. A quantitative implementation of the method developed in the example of one of the microdistricts of Orel’s city is given. The proposed method for assessing the availability of infrastructure facilities to analyze the state of the territory and the viability of urban planning decisions, as well as the feasibility of reconstruction of the territory. The numerical distribution of a comprehensive indicator of the availability of infrastructure facilities and a further assessment of the feasibility of the functions of a biosphere-compatible city allows analyzing the urban design decisions and urban development innovations that contribute to the full development of man and increase human potential.

1. Introduction
The location factor of urban infrastructure becomes critical for creating a comfortable and safe living environment in cities and is fundamental in determining the component of territorial accessibility when implementing a specific function of the city.

From the point of view of the availability of urban infrastructure, it’s possible to evaluate the time provided by the city to each resident to satisfy its needs [1]. The required time depends on the age, social status, ethnic origin and other indicators of the urban population, as well as the development of the transport infrastructure. It is possible to determine the optimal indicators of accessibility from the point of view of human development in the city and make changes in the structure of the city. It is advisable to use the indicator "time given to a person to satisfy their rational needs" as an indicator of planning decisions for master plans and territory planning projects. In this case, it is possible to
provide an availability estimate based on the spatio-temporal availability indicator when implementing a specific city function [2-9]. This indicator will depend on the total time necessary to cover the distance between the two points. To assess the availability of life support facilities, the radius of service to the population by institutions and enterprises located in residential buildings within one block (microdistrict) is proposed as an estimated indicator of territorial accessibility. The radius of public service is divided into the radius of pedestrian accessibility and the radius of transport accessibility [8].

In accordance with the principle of satisfying the rational needs of the population in urban services, the criterion for assessing the territorial and spatio-temporal availability of life-support facilities and socially significant objects for various categories of the urban population can serve as an indicator - the level of accessibility in the implementation of the city's function [8,10-12].

2. Results and discussions

To assess the territorial accessibility of life support facilities and socially significant facilities to residents of a particular residential building [13], the following algorithm for calculating a comprehensive indicator characterizing the level of territorial accessibility of these facilities is presented.

A residential building is located within a certain territorial unit (for example, a quarter, district, etc.). As a result of appropriate monitoring (analysis of project documentation), the actual minimum distances \( R_{ij} \) from the house to the objects included in the group are determined \( D_{ij} \) - the radius of public services. It is convenient to present the obtained data in the form of a 14-component vector \( \mathbf{R}_k \)

\[
\mathbf{R}_k = \{R_{11}, R_{12}, R_{13}, R_{14}, R_{15}, R_{21}, R_{22}, R_{31}, R_{51}, R_{52}, R_{53}, R_{54}, R_{55}, R_{71}\}
\]

where \( \mathbf{R}_k \) is the vector of the set of actual minimum distances from the \( k \)-th apartment building to the nearest objects included in 14 groups for assessing the state of the components \( D_{ij} \) of city functions \( F_i \).

Figure 1 shows circles with standard pedestrian access radius \( \mathbf{R}_{ij} \) for each assessment \( D_{ij} \) group.

To compare the actual distances \( R_{ij} \) of a particular \( k \)-th house with the standard radii of pedestrian accessibility \( \mathbf{R}_{ij} \), is calculated their relationship

\[
a_{ij} = \frac{R_{ij}}{\mathbf{R}_{ij}}
\]
The relations obtained are represented by the components of the vector \( \mathbf{A}_k \)

\[
\mathbf{A}_k = \{a_{k11}, a_{k12}, ..., a_{k71}\}
\]

where \( \mathbf{A}_k \) is the 1st level vector containing the totality of deviations of the actual distances of the \( k \)-th house to significant objects from the standard values of these distances.

Each group of city assessment \( D_j \) by experts is assigned a weight coefficient \( l_{ij} \) characterizing the degree of significance of the assessment group \( D_j \) for the implementation of the city function \( F_i \). These coefficients are also represented by a multicomponent vector \( \mathbf{L}_j = \{l_{1j}, l_{2j}, ..., l_{7j}\} \)

Then, a comprehensive indicator of the territorial accessibility of vital and socially important objects to residents of the \( k \)-th house on the territory of a given district (quarter) can be defined as a scalar product of vectors \( \mathbf{A}_k \) and \( \mathbf{L}_j \)

\[
\eta_{k,s} = \mathbf{A}_k \cdot \mathbf{L}_j = \{a_{k11}l_{1j} + a_{k12}l_{2j} + ... + a_{k71}l_{7j}\}
\]

Note that in the case \( R_{ij} > R_j \) - the indicator \( a_{ij} \) is taken equal to 0, to be exact, the object is unavailable, and in the case \( R_{ij} \leq R_j \) - the indicator \( a_{ij} \) is taken equal to 1.

Thus, accessibility indicators are constructed for all houses in a given district (quarter). The set of indicators \( \eta_k \) \( (k = 1, 2, ..., m) \) can be represented by the \( m \)-component vector of the 2nd level

\[
\mathbf{\eta}_{\text{district}} = \{\eta_1, \eta_2, ..., \eta_m\}
\]

In the case of the same importance of houses, the indicator of territorial accessibility for the population of the entire district (quarter, etc.) will be equal to the average value of indicators of accessibility for houses

\[
\eta_{\text{district}} = \frac{\sum_{k=1}^{m} \eta_k}{m}
\]

(2)

The indicator of territorial accessibility in the city (with the same significance of the districts)

\[
\eta_{\text{city}} = \frac{\sum_{r=1}^{R} \eta_{\text{district}}}{r}
\]

(3)

where \( r \) is the number of districts in the city.

Assessment of the level of spatio-temporal accessibility of life support facilities and socially significant objects for the population of the urbanized territory

\( \mathbf{Z} \) - component contains 7 components, each of which represents some infrastructure necessary for the implementation of the function of the city \( F_i \) \( (i = 1, 2, ..., 7) \).

Each component \( F_i \) of the technogenic component \( \mathbf{Z} \) contains a certain part \( (j\)-th evaluation group \( F_{ij} \)) of the infrastructure: \( F_1 \) contains 2 assessment groups \( F_{11}, F_{12} \); \( F_2 \) contains 1 assessment group \( F_{21} \); \( F_3, F_4 \) - are not standardized; \( F_5 \) contains 4 assessment groups \( F_{51}, F_{52}, F_{53}, F_{54} \); \( F_6 \) - not standardized; \( F_7 \) contains 3 evaluation groups \( F_{71}, F_{72}, F_{73} \). Only ten assessment groups.

To assess the spatio-temporal (transport) accessibility of objects of vital and socially important residents of a particular house, it is proposed to use the following algorithm for calculating a complex indicator that characterizes this interpretation of the concept of “accessibility” of these objects.

The residential building is located within a certain territorial unit (quarter, city district, rural settlement, etc.).

Regulatory requirements for transport accessibility for assessment groups \( F_{ij} \) are adopted different depending on the type of settlement: cities with different populations or rural areas.
The time provided by the city to each resident to satisfy their rational needs can be interpreted as the accessibility of urban infrastructure and evaluated as an indicator of the spatio-temporal (transport) availability [8,12]. A comprehensive indicator should characterize the level of social objects accessibility, engineering and transport infrastructure, public and industrial buildings, buildings and structures, including those in which physical education and sports organizations, cultural and art organizations, recreational facilities and the services they provide are located [14].

A comprehensive indicator of accessibility can be represented by a multicomponent vector, the components $T_{ijk}$ of which are determined empirically (by measuring) the time spent by residents of a particular $m$-th house on the territorial unit in question (for example, a city district) in order to achieve various ways of urban infrastructure in an optimal way $\bar{T}_m = \{T_{i1}, T_{121}, T_{122}, \ldots, T_{731}\}$ where $\bar{T}_m$ - is the vector of the set of actual optimal times to overcome the distances from the $m$-th apartment building to the nearest objects included in ten groups of assessment of the states $F_{ij}$ of the components $Z$.

Figure 2 depicts circles with radii $n_{ijk} \bar{T}$, measured by standard intervals of time to reach the objects of the assessment group $F_{ij}$ from the $m$-th.

![Figure 2. Scheme of normative time intervals for reaching various objects from the $m$-th object.](image)

To compare actual times $T_{ijk}$ with standard times $n_{ijk} \bar{T}$, is calculated their relations for the $m$-th object

$$b_{mijk} = \frac{T_{mijk}}{n_{ijk} \bar{T}} \quad (4)$$

Is represented the obtained relations by the components of the vector $\bar{B}_m = \{b_{m11}, b_{m121}, \ldots, b_{m731}\}$, where $\bar{B}_m$ is the 1st level vector containing the totality of deviations of the actual time values for the $m$-th house from the standard values.

Each assessment group $F_{ij}$ by experts is assigned a weight coefficient $l_{ijk}$ characterizing the degree of significance of the requirement $T_{ijk}$. These coefficients are also represented by components of a multicomponent vector $\bar{L}_m = \{l_{i11}, l_{121}, \ldots, l_{731}\}$.

Then a complex indicator of transport accessibility of the $m$-th house in the territory of a given region (quarter) can be defined as a scalar product of vectors $\bar{B}_m$ and $\bar{L}_m$

$$\eta_{mtr \, acc} = \bar{B}_m \bar{L}_m = \{b_{m11} l_{i11}, b_{m121} l_{121}, \ldots, b_{m731} l_{731}\}$$

**Comment.** The indicator $b_{mijk}$ is taken equal to 0 if $T_{mijk} > n_{ijk} \bar{T}$ - the indicator $b_{mijk}$ is taken equal to 1. A comprehensive indicator $\eta_{mtr \, acc} = 0$ means the inaccessibility of all vital facilities to residents of a given residential building; when $\eta_{mtr \, acc} = 1$ the availability of all objects is complete; when $0 < \eta_{mtr \, acc} < 1$ - partial availability.
In the same way, accessibility indicators are constructed for all houses of a given territorial unit. The set of indicators for these \( n \) houses can be represented by an \( n \)-component vector of the 2nd level:

\[
\vec{\eta}_{d \times acc} = \{\eta_{1acc}, \eta_{2acc}, \ldots, \eta_{nacc}\}
\]

In the case of the same significance of all residential buildings of a given territorial unit (district), the accessibility indicator will be equal to the average value of the accessibility indicators for houses

\[
\eta_{d \times acc} = \frac{\sum_{m=1}^{n} \eta_{m}}{n} \tag{5}
\]

City accessibility indicator

\[
\eta_{city} = \frac{\sum_{l=1}^{r} \eta_{l \text{district}}}{r} \tag{6}
\]

where \( r \) - is the number of districts in the city.

Is provided a numerical implementation of the method for determining the indicators of general accessibility for the infrastructure facilities using the example of one of the city residential areas of the Central Federal District of the Russian Federation [9,15]. Zarechensky residential area is the largest and dynamically developing district in Orel city. As life support objects, the calculation took into account medical organizations (a branch of a children's clinic, a dental office, and pharmacies), as well as trade, public catering and consumer services enterprises (a shopping complex, food and non-food stores, and public catering establishments).

In accordance with the proposed criterion for assessing the territorial and spatio-temporal accessibility of life support facilities and socially significant objects to various categories of the urban population, a comprehensive indicator of the territorial accessibility of vital and socially important objects to residents of this microdistrict is equal to:

\[
\eta_{acc} = 0.83 \cdot 0.3 + 1 \cdot 0.1 + 0.71 \cdot 0.2 + 1 \cdot 0.1 + 1 \cdot 0.1 + 1 \cdot 0.1 + 1 \cdot 0.1 = 0.89
\]

The microdistrict infrastructure in terms of life-supporting functions is represented by a polyclinic, shopping centers, food and non-food stores and catering enterprises. The security of almost all facilities is in accordance with regulatory requirements, and the availability is different: from partial to full. In general, a comprehensive measure of accessibility is high.

The calculation allows illustrating the assessment of compliance with the current standards of urban design [16].

3. Conclusion

The proposed accessibility assessing methodology of infrastructure facilities to the population along with other prerequisites for the modernization of urban planning activities [17-20], allows analyzing the state of the territory with the possibility of evaluating the effectiveness of urban planning solutions, as well as the feasibility of substantiating the reconstruction of existing buildings.

The results obtained emphasize the need and feasibility of further developing scientifically based guidelines to ensure a safe and comfortable human environment when planning new urban residential areas and developing existing ones based on the principle of implementing biosphere-compatible urban functions to meet human needs in the best possible way.

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