# ESTIMATION OF TRANSPORT ACCESSIBILITY LEVEL ON THE BASIS OF FORECAST MODELS

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## ABSTRACT

The article presents a methodology for calculating the parameters of transport accessibility level in the territories of large cities. With the help of the proposed model, it is possible to assess the situation with the volume of transport correspondence, as well as the change in the indicators of accessibility after the implementation of individual scenarios for development of transport infrastructure. The methods for calculating modeling, forecasting the road load, introducing zoning principles give specialists in the field of urban planning, transport planning and traffic management in the cities a clear tool for formation of a reliable transport system.


*Keywords: urban transport system, modeling, organization of traffic, transport accessibility of territories, transport accessibility level, zoning, infrastructure, civil engineering, urban geography.*

**Background.** *The creation of an efficient transport system of the city directly meets the task of improving the quality of life in its territories. The tools for formation of such a system are, first of all, transport planning, organization of traffic, public passenger transportation network and parking policy.*

*In the system of costs of time and money, the quality and purpose of transport systems should be considered from two sides:*

- *ensuring transport accessibility;*
- *reduction of transport costs [ed. note: e.g. affordability].*

*The first criterion is estimated through the person's perception of the possibility of carrying out the necessary transport correspondence. The second criterion is easily formalized in terms of the amount of time or money a person spends on his transportation needs.*

*The overall indicator of the quality of the functioning of the transport system is expressed through the amount of transport costs – the average time for implementation of transport correspondence, which is calculated for the city as a whole, averaging takes place for all correspondence.*

*When carrying out a transport analysis of the territory of a large city, one can note a significant uneven use of the urban area. With the increase in distance from the center, not only the density of the developed territories and land under real estate objects is reduced, but also the total balance of the areas occupied for private needs and public purposes, including the maintenance of the street-road network (SRN). A similar situation is observed with the development of public urban passenger transport infrastructure. That is, the central areas of the city have a large transport dependence, in contrast to the territories of the periphery. And, consequently, the existing balance of the use of the territory, in particular, the diversion under the transport infrastructure – is economically justified.*

*However, this leads to a difference in assessing the quality of the functioning of the transport system by people living in different urban areas. As in analogy with other engineering networks, service facilities, etc., residents assess their transport security based on the surrounding realities.*

*On the one hand, differences in these assessments give rise to social conflicts; on the other hand, the equalization of transport accessibility in all territories is economically unjustified. It becomes obvious that improving the quality of the transport system of the city is not only a matter of forming a worthy offer, but also creating conditions for changing transport demand [1].*

**Objective.** *The objective of the author is to consider estimation of transport accessibility on the basis of forecast models.*

**Methods.** *The author uses general scientific and engineering methods, comparative analysis, evaluation approach, mathematical apparatus.*

**Results.**

***Differentiated indicators***

*A separate assessment of the transport accessibility of the territory implies the division of the total area of the city into transport zones, which are of four types. It is proposed to divide the territory according to the following principle [2]:*

*1. City center (zone A). Zones of this type are characterized by maximum business activity.*

*2. The central areas adjacent to the city center (zone B). This is dominated by high-rise buildings and multifunctional use of the territory.*

*3. Remote areas (zone C). They have their own centers of business and social activity, in the long term – transformation into self-sufficient settlements and autonomization.*

*4. Extensive areas with low population density and low-rise buildings (zone D).*

*An example of zoning is shown in Pic. 1.*

*It is proposed to introduce the concept of «transport accessibility level of the territory» when assessing the quality of the functioning of the transport system. Ideally, any city should be a set of conditional territories (zones) with equal transport accessibility. That is the purpose of the city's transport policy is to achieve equalization of transport accessibility.*

*For formalization of the concept of transport accessibility level, it is proposed to estimate the volumes of transport correspondence and the time of their realization in separate urban areas in three types of movements: transit, entry, internal traffic. We illustrate this in Pic. 2 [3].*

*Through the area under study r routes pass, which connect the centers of transport areas: A, B, C, D. There are three types (S = 1, 2, 3) of passage:*

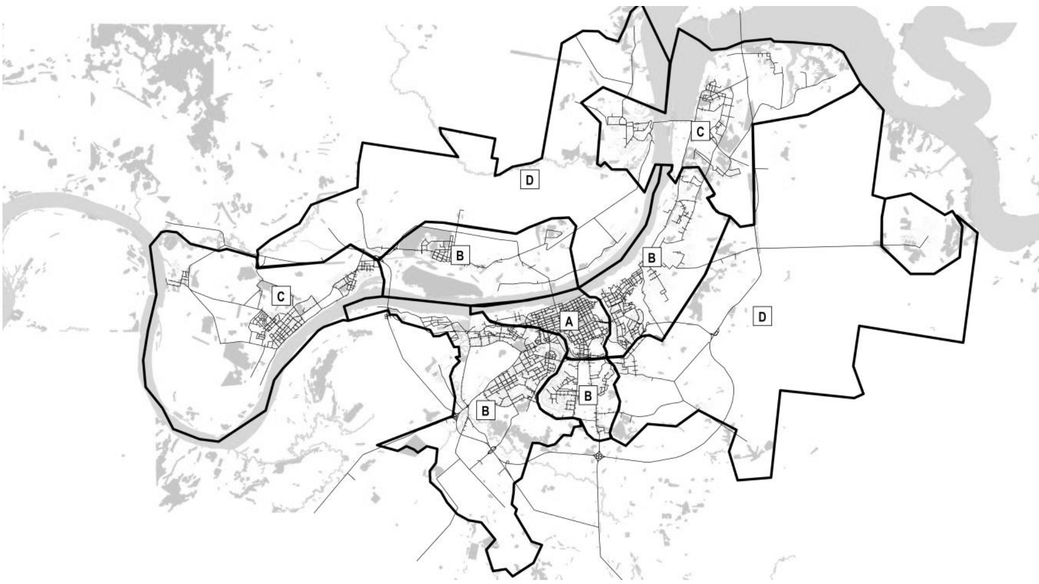
*1st type (A – B) transit–route crosses the boundaries of the studied region at two points;*

*2nd type (B – C) entry/exit – the route crosses the border at one point;*

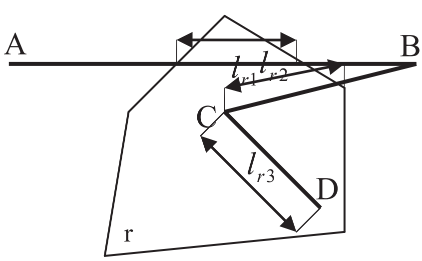
*3rd type (C – D) internal traffic – the route does not cross the boundaries of the studied area, and the centers are inside it.*

*For each type of movement, a differentiated indicator of the transport accessibility level of the territory will be introduced [4]:*

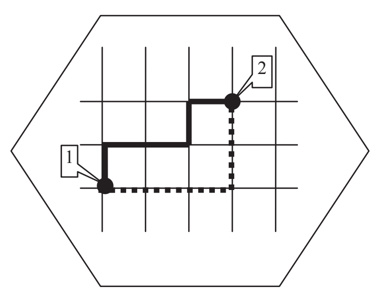
*1. Transport accessibility level of the territory (TERTAL).*




*Pic. 1. An example of zoning of the city.*




*Pic. 2. Types of correspondence passing through the transport zone.*




*Pic. 3. A diagram illustrating the principle of calculating the TERTAL parameter.*

*2. Transport accessibility level of access to the territory (ATAL).*

*3. Transport accessibility level of transit through the territory (TRTAL).*

*Each of three indicators characterizes the transport accessibility level of the territory in terms of its ability to meet the transport demand associated with the appropriate type of movement and is calculated as the average time for the implementation of transport correspondence in the study area.*

*Transport accessibility level of the territory shows the situation from the point of view of realization of internal traffic.*

*Transport accessibility level of access to the territory – shows the situation in terms of the implementation of entry into the territory under consideration.*

*Transport accessibility level of transit through the territory – shows the situation in terms of the possibility of through traffic.*

*To equalize the transport accessibility level of the territories of the city, it is necessary to separately evaluate the contribution of each type of indicators to the overall indicator of the objective function of the transport system – the average time for the implementation of transport correspondence. And the latter will also have their own weight coefficients.*

*As a theoretical justification for the expediency of such an approach, several points should be noted that illustrate the imbalance in the transport systems of many cities between the needs for traffic and the nature of the use of the existing transport infrastructure.*

*Thus, the growth of transport infrastructure in the central parts of the city does not affect its loading in any way, while the traffic intensity is growing, and the balance of types of transport correspondence – internal, border and transit – is changing. With the growth of the transport supply, the balance is changing towards an increase in the share of sales of transit correspondence.*

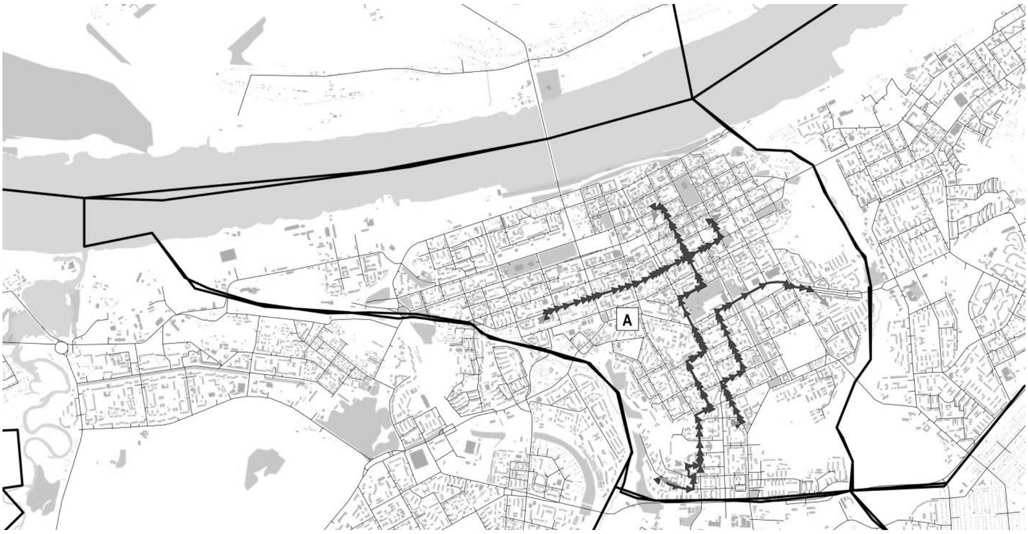
*On the other hand, the growth of transport infrastructure in peripheral areas, on the contrary, leads there to the growth of internal correspondence [5].*

***Transport accessibility level of the territory***

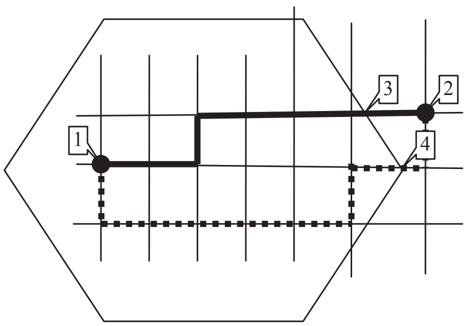
*To identify areas of equal transport accessibility level, the concept of «transport accessibility level of the territory» should be formalized for the beginning.*

*Transport accessibility level of the territory (TERTAL) will be determined as the average time for the implementation of internal correspondence of the studied zone [6].*

*A diagram illustrating the choice of correspondence, as well as the principle of calculating the TERTAL parameter, is shown in Pic. 3. Hexagon is*




Pic. 4. Fragment of the forecast model for determining the parameters of the transport accessibility level of zone A.



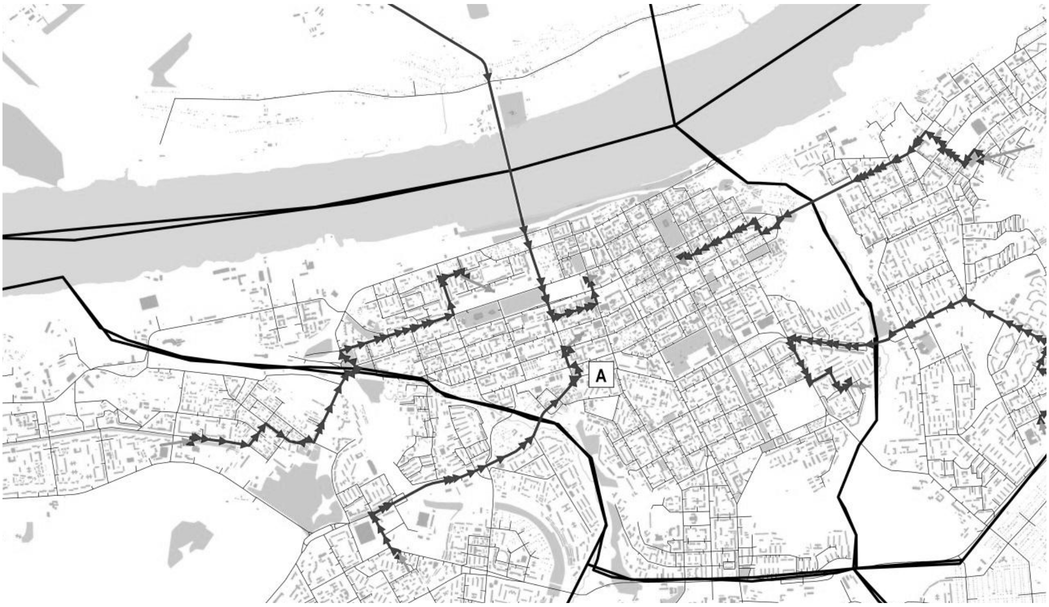

**Pic. 5. A diagram illustrating the principle of calculating the ATAL parameter.**

*the boundary of the studied area (the territory of the city). The grid inside is a fragment of the graph of the street-road network. As noted, the correspondence in question has a source and purpose (source and sink) within the designated zone. In the above diagram, these are points 1 and 2. There are many ways to implement correspondence between them. In Pic. 3 examples of movements from point 1 to point 2 are marked by a thick line and a dotted line. Each of the possible paths can be assigned a number.*

*In Pic. 4 there is a fragment of the forecast model. The arrows mark out the paths within the boundaries of the first zone – the urban center (zone A) [7].*

*There are two ways to determine transport accessibility level of the territory.*

*The first method presupposes, as the sought-for value, the average time for the realization of internal*




**Pic. 6. Fragment of the forecast model for determining the parameters of transport accessibility level of access to the territory for zone A.**

*correspondence in the studied zone, according to the number of individual correspondence and their length. In this case, the value of the transport accessibility level of the territory is given by the formula:*

$$TERTAL=\frac{\sum_k x_{kCD}\cdot l_{kCD}\cdot t_{kCD}}{\sum_k x_{kCD}\cdot l_{kCD}} \qquad (1)$$

*where TERTAL – transport accessibility level of the territory, sec;*

*k – sequence number of the path of CD type;*

*$x_{kCD}$ – number of correspondence on the k-th path of CD type per day;*

*$t_{kCD}$ – time of completion of correspondence on the k-th path of CD type, sec;*

*$l_{kCD}$ – length of the k-th path of CD type, m.*

*The second method of calculation is aimed at obtaining the average weighted by the number of correspondence, the ratio of their lengths to the time of implementation. In this case, the value of the transport accessibility level of the territory will be measured in m/s:*

$$TERTAL=\frac{\sum_k x_{kCD}\cdot l_{kCD}}{\sum_k x_{kCD}\cdot t_{kCD}} \qquad (2)$$

*Both indicators – time and length-to-time ratio – characterize the quality of the city's transport system in a single territory relative to the needs of the population. These values will show either the average time spent by a resident to make intra-zonal correspondence, or the speed at which the transport system allows him to perform them. The obtained pictures, on the one hand, will show the transport offer existing in the studied area, and on the other hand – will allow to assess the potential for changing the structure of transport demand in the territory. After all, it is understandable that an increase in the parameter of the transport accessibility level of the territory (speeding up, or reducing the time for completion of correspondence) will also stimulate a change in the structure of demand in favor of internal correspondence.*

*Transport accessibility level of access to the territory*

*Transport security of access to the territory (ATAL) will be defined as the average time for the implementation of border correspondence within the studied zone.*

*The principle of selecting correspondence for the calculation of the ATAL is shown in Pic. 5. Hexagon is the boundary of the studied area (the territory of the city). The grid inside and outside the border is a fragment of the RSN graph. The correspondence considered has a source inside the studied area – point 1. Outflow outside the zone, in the scheme it is the point 2. There can be many ways for realization of correspondence. In the picture, examples of movements from point 1 to point 2 are marked by a thick line and a dotted line. Thus, in the calculation of ATAL, only the parts of the paths passing inside the zone are considered, say, from point 1 and to exit points beyond the boundaries of the zone (points 3 and 4). Each of the possible ways of implementing correspondence can be assigned a number.*

*Pic. 6 presents a fragment of the forecast model for determining the parameters of transport accessibility level of access to the territory. The arrows mark the border lines within the boundaries of the first zone – the city center (zone A).*

*In order to calculate the transport accessibility level of access to the territory, as in the determination of transport accessibility level of the territory (TERTAL), there are two possible ways. The first confirms time priority of movement:*

$$ATAL=\frac{\sum_k x_{kBC}\cdot l_{kBC}\cdot t_{kBC}}{\sum_k x_{kBC}\cdot l_{kBC}}, \qquad (3)$$

*where ATAL is transport accessibility level of access to the territory, sec;*

*k – sequence number of the path of BC type in the studied zone;*

*$x_{kBC}$ – number of correspondence on the k-th path of BC type per day;*

*$t_{kBC}$ – time of completion of correspondence on the k-th path of BC type inside the territory, sec;*

*$l_{kBC}$ – length of the k-th path of BC type inside the territory.*

*The second method gives an advantage of speed, m/s:*

$$ATAL=\frac{\sum_k x_{kBC}\cdot l_{kBC}}{\sum_k x_{kBC}\cdot t_{kBC}} \qquad (4)$$

***Transport accessibility level of transit***

*As for the third indicator of security (TRTAL), it is defined as the average time for the implementation of transit correspondence passing through the territory of the studied zone.*

*The principle of selecting correspondence for the calculation of the TRTAL is shown in Pic. 7. Hexagon is the boundary of the studied area (territory of the city). The grid inside and outside the contour is a fragment of the SRN graph. The correspondence in question has a source and an outflow outside the zone, points 1 and 2. There are many ways for the implementation of correspondence. In the diagram, examples of the movements from point 1 to point 2 are marked by a thick line and a dotted line. When calculating TRTAL, only the parts of the paths that pass inside the zone are considered, in our case these are the sections between the exit points from zones 3–4 and 5–6. Each of the possible paths can be assigned a number.*

*Pic. 8 shows a fragment of the forecast model for determining the parameters of transit transport accessibility level. Arrows highlight transit routes within the boundaries of the first zone – the city center (zone A).*

*To determine the transport accessibility level of transit through the territory, similar to TERTAL and ATAL, two methods are possible [8]:*

$$a)\ TRTAL=\frac{\sum_k x_{kAB}\cdot l_{kAB}\cdot t_{kAB}}{\sum_k x_{kAB}\cdot l_{kAB}}, \qquad (5)$$

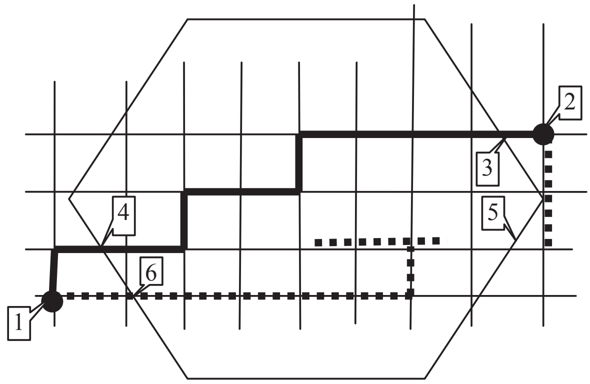
*where TRTAL – transport accessibility level of transit through the territory, sec;*

*k – sequence number of the path of AB type in the studied zone;*

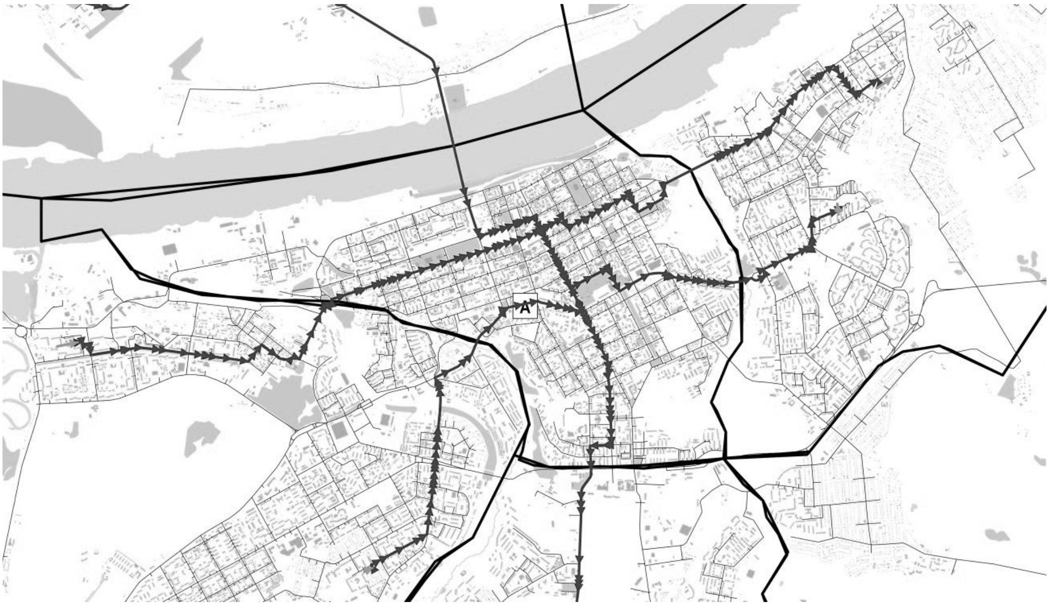
*$x_{kAB}$ – number of correspondence on the k-th path of AB type per day;*

*$t_{kAB}$ – time of completion of correspondence on the k-th path of AB type, inside the territory, sec;*

*$l_{kAB}$ – length of the k-th path of AB type, inside the territory, m.*




***Pic. 7. A diagram illustrating the principle of calculating the TRTAL parameter.***




***Pic. 8. Fragment of the forecast model for determining the parameters of transit transport accessibility level through the territory of zone A.***

b) $$TRTAL = \frac{\sum_k x_{kAB} \cdot l_{kAB}}{\sum_k x_{kAB} \cdot t_{kAB}}, \quad (6)$$

*where TRTAL – transport accessibility level of transit through the territory, m/s.*

*The first method gives a weighted average in terms of the number of individual correspondence and their length, the value of time for implementation of internal traffic in the studied area, measured in seconds. The second method is a weighted-by-correspondence ratio of the lengths of correspondence by the time of their implementation, speed in m/s.*

*From the point of view of a man's internal perception of transport accessibility, various types of trips by their importance stand in a certain sequence for each of the territories:*

*• internal traffic in the zone – parameter of transport accessibility level of the territory (TERTAL);*

*• border traffic in the zone – parameter of transport accessibility level of access to the territory (ATAL);*

*• transit traffic – parameter of transport accessibility level of transit through the territory (TRTAL).*

*Realization of opportunities in the internal traffic is much more important for a person's life than moving with border targets or transit traffic through the territory where he lives. The latter in the understanding of residents is a certain negative factor. Having split the city into separate transport zones, one can imagine each of the zones as an independent city with its own transport system. It is obvious that the assessment of the quality of such a local system will be based on the evaluation of the time for the implementation of internal correspondence, rather than border, and especially not transit.*

*The originality of the differentiated approach to assessing the quality of urban transport systems is that correspondence is divided into types. For each territory, the transport accessibility level, the level of access to the territory and the possibilities for transit through the territory are calculated. As a result of any changes in the transport offer or transport demand,* *it is likely to see how the changes have affected the territory.*

***Integral indicator***

*Having differentiated indicators of the quality of the functioning of the transport system, it is possible to formulate an integral indicator of transport accessibility level for a particular i-th territory [9].*

*This will be some linear function of the differentiated parameters TERTAL, ATAL and TRTAL:*

$$TI_{avi} = f(TERTAL, ATAL, TRTAL). \quad (7)$$

*In view of the fact that it is important for each person exactly what types of correspondence are made within the territory of his residence, it is necessary to introduce coefficients that will take into account people's preferences. These coefficients are $\beta_{AB}$, $\beta_{BC}$, $\beta_{CD}$. And the type of correspondence plays the same role, regardless of the zone where a person lives. In this regard, the values of the coefficients for different territories will be the same. Then:*

$$TI_{avi} = \beta_{AB}\, TRTAL_i + \beta_{BC}\, ATAL_i + \beta_{CD}\, TERTAL_i, \quad (8)$$

*where $TI_{avi}$ – integral indicator of transport accessibility level of a separate i-th territory; $\beta_{AB}$, $\beta_{BC}$, $\beta_{CD}$ – weights of differential quality indicators of TRTAL, ATAL and TERTAL systems.*

*The received indicator $TI_{avi}$ characterizes the transport security of some parts of the city. To assess the transport accessibility level of its entire territory, the value of the parameter «integral time for the implementation of transport correspondence» will be used [10]. It is calculated as a linear combination of integral indicators of the transport accessibility level of individual territories. Since the average time of correspondence in a zone depends on the length of the SRN, it is necessary to take this into account when determining the parameter of the integral transport accessibility level of the whole city, in particular introducing the weight coefficients $\alpha_1$, ..., $\alpha_{10}$ [11]. Then the average integral time for the implementation of transport correspondence, taking into account the coefficients for the territories, will be:*

$$TI_{av} = \alpha_1 TI_{av1} + \alpha_2 TI_{av2} + ... + \alpha_{10} TI_{av10}, \quad (9)$$

*where $TI_{av}$ – average integral time of realization of transport correspondences for a city;*

*$TI_{av1}$ – average integral time of realization of transport correspondences for the i-th zone;*

*$\alpha_1$, ..., $\alpha_{10}$ – weight coefficients, calculated as follows:*

$$\alpha_i = \frac{S_i}{\sum_{j=1}^{10} S_j}, \quad (10)$$

*where $S_i$ – are of SRN inside the zone i.*

*For each zone, it is possible to determine the «transport accessibility level deficit» by comparing the values of $TI_{av1}$ with the value of $TI_{av}$. In the case when the differences $TI_{av} - TI_{avi}$ are negative, one can speak of a transport accessibility level deficit of the studied zone, since the costs of making correspondences in it exceed the city average [12].*

**Conclusion.** *The use of such an integral indicator together with the indicator of the average time for the implementation of transport correspondence and differentiated indicators makes it possible to assess both the existing transport accessibility level of the territory and its change after the implementation of various scenarios of transport demand and transport supply.*

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