Parameters and resource potential of the territory of populated places in the zone of influence of stopping points

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Abstract. The authors did not set a goal to make a comprehensive analysis of all aspects of the formation and functioning of the settlement territories in the zone of stopping points influence.The article is a review and a problem. It provides an overview and analysis of research directly or indirectly related to the problem under consideration. The results of multivariate calculations using the regulatory documents of Ukraine are presented: parameters of the zones of transport lines and stopping points influence (width of the zones of influence, total area of construction and area of residential construction in the zone of influence of one stopping point), resource potential (housing stock, population) for the largest, large, large and small settlements and their zones (central, middle, peripheral). The performed calculations show that the territories of settlements in the zone of influence of stopping points occupy an important place in the planning structure and vital activities of settlements due to their significant resource potential − territory, population, housing stock, as well as the close relationship of their structural parameters with the parameters of the transport infrastructure. which indicates the need to consider them as a whole.

1 Introduction

The network of streets and roads and lines of passenger public transport are the basis, the framework of the functional and planning structure of the settlement. Passenger flows are formed and absorbed on the territory within the pedestrian reach of the stop points (zone of influence of the stop points), the parameters of which depend on the parameters and human resources of the zones of influence of the stop points. Transport infrastructure parameters (density of public passenger transport lines, distances between stops) are interconnected with the parameters of the influence zones of passenger public transport lines and stops and their resource potential. Therefore, the study of the relationship between the parameters and the

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resource potential of the indicated zones of influence is important for understanding the principles of forming the functional and planning structure of the settlement as a whole.

The authors did not aim for a comprehensive analysis of all aspects of the formation and functioning of these territories. The article is a review and a problem. It provides an overview and analysis of studies directly or indirectly related to the problem under consideration, only the results of parameter calculations and resource potential of the studied territories, performed using regulatory documents [1-6], are given, the importance of these territories in the planning structure and life activities is determined settlements, the main directions of research are planned, aimed at improving the calculations of parameters and resource potential of these territories.

Unfortunately, the authors did not find any publications directly related to the research topic. There are publications on the study of individual parameters of the planning structure of the city, which allow to conduct research and calculation of parameters and resource potential of the territory of the zone of influence of stopping points. Such parameters of the planning structure of the city are: the density of routed passenger transport lines in built-up areas; the distance between stops on scheduled passenger transport lines; radius of reach to stopping points and others given in normative documents on planning the territories of populated areas [1, 2] and periodical literature.

The density of urban route passenger transport lines in built-up areas [1] is determined, taking into account their functional use and the intensity of passenger flows, within the limits of 1.5-2.5 km/km^2 , in the central areas of the larger ones and large settlement, the density of the network is allowed to increase to 3,5 km/km^2, actual - vary widely, for example, in Zaporizhzhia it is equal to 1.56 km/km^2 [7], Vinnytsia - 1.73 km/km^2 [8], the city of Sumy - 1.33 km/km^2 [9], Odesa - 27.7 km/km^2; Bilhorod-Dnistrovsky -1.3 km/km^2; Izmail - 3.96 km/km^2; Illichivsk - 3.84 km/km^2; Kotovsk - 6.0 km/km^2; Yuzhne - 0.42 km/km^2 [10].

The distance between stops on routed passenger transport lines within the territories of populated areas is established by norms [1] taking into account the provision of the radius of pedestrian reach, as well as the speed of communication on the routes. Within the built-up area, the distance between stops on the routes of buses, trolleybuses and trams, the vehicles of which operate in normal mode, is taken in accordance with table 10.4 [1], depending on the group of settlements and the zone of urban planning value of the territory from 250 to 800 m. For express buses, high-speed trams, the distances between stops are taken to be 1.5-2.0 times greater than those indicated in table 10.4 [1]. Unfortunately, the dependence of the connection speed on the distance between stops is not substantiated by calculations and is not standardized by this document.

The distance between stops is determined depending on the density of urban route transport lines and the standardized distance of pedestrian reach to route transport stops, taking into account the requirements of regulatory documents [3, 5] regarding their location relative to areas of intersections and junctions and intersections of highways; pedestrian crossings; stopping points of various types of public transport, objects and nodes of mass attraction of the population: places of employment, shopping centers, educational, sports and entertainment institutions, railway stations, locations of recreational, tourist and walking areas and other requirements for the location of stops.

In the publication [11], a model for determining the optimal length of the run on urban passenger transport routes was considered and the optimal length of the run in the range of 463-447 m was obtained as a result of the calculation, which, according to the authors, will allow in the future when organizing new passenger routes to locate stopping points with minimum costs of society. The basis of the calculations is the minimization of the total costs of society related to the operation of the stop by optimizing the length of the race.

In the publication [12], the model for determining the length of the journey on city passenger transport routes is considered and the results of the modeling of the journey length are given, taking into account the change in the amount of passenger flow at different values of the cost of walking. Unfortunately, the target function given in the publication is not disclosed by components, and the author sends the reader to the bibliographic list of this publication. It is not clear from the publication which passenger flow is considered - on a separate race or on the route as a whole. It is also known that a characteristic feature of passenger flows is their unevenness, they change by time (hour, day, day of the week, season), as well as along the route. Therefore, the practical significance of the optimal parameters of race lengths that change in time is not clear.

Due to the large number of factors affecting the placement of stops along the public transport route, it is not possible to establish the same distances between them and in reality the distribution of distances is stochastic in nature.

The analysis of the model of route networks of passenger transport of such cities as Sumy, Kryvyi Rih, Kharkiv and Kyiv, carried out [13] taking into account that the distances between stopping points are a random value, revealed the following.

The minimum distance between stopping points is 0.043 km (the city of Sumy), the maximum ─ 12.53 km (the city of Kyiv), the average value ─ from 0.554 km (the city of Sumy) to 0.746 km (the city of Kryvyi Rih), the root mean square deviation ─ from 0.578 km (Kryvyi Rih city) to 0.733 km. (city of Sumy), dispersion from 0.334 (city of Kryvyi Rih) to 0.537 (city of Sumy). The research was carried out in general for all types of transport (bus, trolleybus, tram), without taking into account the organization of traffic on the route (a regular route, where stops are provided at each stop; a shortened route, which is introduced for a certain time, “peak” time; express route , where stops are provided at the starting and ending points, peak hours; semi-express, where stops are provided at places of accumulation of passengers) and also without taking into account the zone of the settlement, as a result of which significant deviations in the characteristics of the distances between the stopping points were obtained, which makes it impossible to use this study for calculation of parameters and resource potential of the territory affected by stopping points.

In studies [14], the optimal length of the race was obtained under the condition that the amount of public costs associated with the operation of the stop point will be minimal. The calculation is based on the variable functions of passenger flows along the entire length of the route, obtained by the method of surveying passenger flows. The publication does not specify the value of the optimal length of the race. The conditions of the survey of passenger flows are not specified - peak hours (morning or evening hours), average during the day, time of year. The effect of fluctuating passenger traffic on the optimal distance between stops has not been covered (or researched).

The safest location of the stop point relative to the road intersection is also proposed, depending on the intensity of traffic flows and pedestrians at the conflict point of the pedestrian crossing.

Publications [15-17] also consider the influence of the factors of the urban passenger transport system on the length of the journey, which ensures a minimum of total costs of society. The authors of the study [15] also consider the optimal length of the race on the current length of the route to be the length that ensures the minimum total costs of society related to the operation of the stop. The optimal length of the race, calculated by the authors according to this criterion, is 800 m for a following passenger flow of 10,000 passengers/day, taking into account the costs associated with the route trip of a passenger in a vehicle, the costs associated with maintaining a stop point 100 hryvnias/day and emissions of harmful substances from exhaust gases of city vehicles.

The publication [18] considers a hierarchical method of optimizing the location of bus stops in the context of multimodal transport services. Three types of bus stops are hierarchically defined, which include connecting stops, key stops, and regular stops. Stops connecting to other public transport facilities are generated manually. Key stops and common stops are optimized using coverage models and are accordingly matched against centralized network performance and potential demand. A case study of the central district of Uban, China shows that a hierarchical approach can create a more efficient stop allocation. After optimization, instead of 733 stops, 650 remained. The reduction of stops was achieved due to the redistribution of their number between central and peripheral areas.

The publication [18] also gives percentages of territory and population coverage depending on the size of the selected buffer zone (impact zone, walking distance) of the stop. With the growth of the buffer zone, the coverage of the territory usually increases and at 500 m reaches 70% for the coverage of the territory, population coverage − 90% in the optimized version.

Analyzing the obtained data, the authors of the publication [18] claim that the optimization result is beneficial only if we consider the service distance over 400 m. The nature of the redistribution of distances between stops after the optimization took on a different form. While existing stopping distances range from 200 to 1000 m, the most optimized distances are in the range of 500 to 900 m.

The number of distances from 300 to 1000 m has been increased, the number of distances from 300 to 400 m has been increased most significantly, and distances up to 1200 m have been added.

The publication [19] provides an analysis of the distances to stops and the time spent approaching them by passengers of urban passenger transport in autonomous Norwegian cities with a population of 28,000-1,020,000 inhabitants (Harmar, Kristiansani, Stavanger, and Oslo)

The initial data were obtained by surveying passengers at public transport stops, in public transport and by e-mail.

The following results were obtained: the time to reach city passenger transport stops is 4.1-6.0 minutes on average, and 6.6-8.6 minutes to train stations; the distance is, respectively, 328-520 m and 528-688 m. The distance to city passenger transport stops increases as the size of the city increases. A short distance to stops increases the likelihood of using public transport instead of private transport for commuting.

The publication [20] investigates the walking distance to public transport stops in the city of Sydney, Australia. Diagrams of the distribution of distances covered by Sydney residents to public transport stops are presented. These distances are in the range of 200-1700 m. The highest frequency is recorded in the range of 200-900 m, the peak is 600 m.

A 2020 survey in Germany [21] shows that people prefer a walking distance to a bus stop of between 5 and 10 minutes or approximately 0.25 to 0.5 miles. Less than 10 percent of respondents say they will walk 15 minutes to catch a bus. Depending on the type of transport, respondents are less willing to walk to get to a bus or tram than to a train or metro station. Here, obviously, the ratio of the distance and speed of the trip with the distance and duration of the walking approach to the stop in different types of transport has an influence. Disparities are also observed in urban and suburban settings. On average, people from urban/commercial areas are willing to walk about 15% less to get to bus/subway stations than their suburban counterparts.

The average distance for an “on-demand” landing according to a survey [21] is ~550 feet, or 2-3 minutes. But, as with fixed-route services, the walking distance to boarding can vary by location and use case: the average walking time for rural areas can be up to 8-10 minutes, while for dense urban services it can be less minutes

In the publication [22], the authors note that the zone of pedestrian reach is usually determined by the “empirical rule”, therefore, in different countries there are different parameters and methods of its determination. A distance of 400 to 800 m or 10 to 15 minutes of walking time to the stop is generally accepted.

According to the transport plan of the city of Munich [22], the service area of the central business district for metro stations is 600 meters, and for trams and buses - within 300 meters. The tram and bus service area is considered to be 400 meters within the high-density zone. In a low-density area, the service area is almost 1,000 meters for the subway and 600 meters for a tram or bus.

The purpose of the scientific work [22] was the study of the actual walking distance to public transport stops and a report on the justification of the route choice by passengers. A systematic case study was conducted following an individual paper-based survey in a German city (Munich).

In order to collect accurate data, in addition to own answers, it was set up a geospatial technological environment, such as a digital map, in a smartphone application (ESRI − ArcGIS Collector).

Geospatial analysis showed that the service area is different for different categories of stations. For the urban zone category, most respondents walked within 300-600 meters. While in the category of predominantly residential and commercial areas, respondents walked further than the threshold prescribed by the planners, and their walking range was mainly between 600 and 1000 meteres. On the other hand, in the third category, which is in the suburbs with low population density and less availability of modes of transport, most respondents walked about 1000-1500 meters and even 1500-2000 meters at one of the stations (Deisenhofen). Walking times to stations in the suburban area range from 1 to 25 minutes, while walking times for stations in the central part of the city range from 1 to 15 minutes. Geospatial analysis showed that the service area is different for different categories of stations. For the urban zone category, most respondents walked within 300-600 meters. While in the category of predominantly residential and commercial areas, respondents walked further than the threshold prescribed by the planners, and their walking range was mainly between 600 and 1000 metres. On the other hand, in the third category, which is in the suburbs with low population density and less availability of modes of transport, most respondents walked about 1000-1500 meters and even 1500-2000 meters at one of the stations (Deisenhofen). Walking times to stations in the suburban area range from 1 to 25 minutes, while walking times for stations in the central part of the city range from 1 to 15 minutes.

Almost half of respondents (40%) said they would be willing to walk between 5 and 10 minutes to a bus, and less than 10% of people said they would walk 15 minutes to catch a bus. In general, respondents in suburban areas on average preferred to walk longer to buses. In addition, there was a different preferred walking time at almost every station. Some respondents would like to walk only 1-2 min to the bus, and some − 15-20 min.

The article [23] analyzes the influence of the planning structure of the street network and the location of the Madrid metro stations on the area of the coverage area, population coverage depending on the proximity ranges, on population employment, quality of access and potential demand.

The results of the analysis of the real situation regarding the environment of metro stations were compared with the results obtained from four hypothetical street networks representing four models of the urban planning structure typical of modern cities. When calculating the hypothetical models, the current structure of the population and jobs remained unchanged.

The study was conducted only on lines and stations within the municipal area of Madrid. In total, 199 stations belonging to 12 network lines were analyzed.

For the study, actual indicators of population and employment in existing urban areas were taken and changes in the structure of streets were modeled. The purpose of the study was to measure the impact of different street network structures on the area around the stations, taking into account the current structure of population and employment distribution. For this, real data on population and employment in existing urban areas were taken and changes in the street structure were modeled. The street network and building locations were downloaded from the National Geographic Institute (Cartociudad-National Geographic Institute). All buildings in the city were represented on the map as points, had information on the number of permanent residents and the number of jobs.

The information was processed using a Geographic Information System (GIS), in this case ArcGIS 10 (ArcINFO) and its Network Analyst module, using network distances to delineate station coverage areas.

The data of the 400-meter and 800-meter service zones were calculated. At the same time, for each option of street networks, average walking distances to the nearest station from the place of residence and place of work were calculated using the ArcGIS Closest Facility to link each building to the nearest station.

The calculation of population coverage and employment was based on the increase in capacity index, which takes into account the population and employment at a certain distance from the stations. The term “Service Zone” was used to demarcate the influence zones of stations in 100-meter ranges up to 1200 meters. The number of people and jobs that fall into the ranges is then calculated.

The main contribution of the considered article is the methodology that was used to calculate the impact of the urban planning structure on the coverage and potential demand for transportation by the metro networks of Madrid. It is also of great interest when studying the parameters and resource potential of ground public transport stops.

In the textbook [24] much attention is paid to defining the relationship between the radius and the walking distance, which only complicates the determination of the walking distance and makes it more uncertain. According to the authors, in this case, it is more expedient to determine the distance of pedestrian reach as the sum of the distance to the transport line (taking into account the coefficient of non-straightness) and the distance to the stop on the sidewalk along the transport line. The manual also provides an empirical formula for determining the average value of the zone of pedestrian reach by A.H. Zilbertal without references to the original source, which is later cited by other authors in their publications, already referring to the “Manual” [24]. Obviously, this is a monograph [25] published in 1937, so the empirical studies given in this monograph hardly correspond to the current state of urban planning. Based on regulatory documents, the authors of this publication present their interpretation of the average value and limit parameters of pedestrian reach.

All the above publications are devoted only to certain aspects of the study of the zones of influence of stopping points, while the research was carried out in the conditions of existing settlements. The authors set a goal to investigate the peculiarities of the formation of zones of influence of stopping points on the basis of the averaged indicators given in the relevant normative documents.

2 Methods

The basis of the calculation of the parameters and resource potential of the territory of the settlement in the zone of influence of the stopping points are the indicators given in the normative documents [1-6]. These documents are the result of the work of leading scientific and design institutions on the generalization of many years of domestic and foreign experience in urban planning.

The following main indicators were used for calculations: 1) density of scheduled passenger transport; 2) distance between stops; 3) walking distance (radius); 4) the number of floors of the building; 5) population density and others given in the calculation tables.

In addition to the zone of influence of stopping points, we introduce a new concept − the zone of influence of the transport line, which is defined as the territory located along the transport line and equal to the area of the territory in km 2 assigned to 1 km of the transport line.

For calculations, we enter the following marks:

δ − density of scheduled passenger transport lines, km/km^2 [1, 2];

L_1 – distance to the route passenger transport line, m;

L_2 – part of the walking distance to the stop, which runs along the sidewalk along the transport line;

L_p – distance between stops (length of the race), m [1, 2];

B – road width, m [5];

B_{vul} − street width in red lines [1, 2];

$B_1 = 1000/\delta$ − the width of the zone of influence of the transport line, m;

B_2 – the width of the zone of influence of the stopping points, m;

$B_{zab.}$ − width of the building zone within the zone of influence of the transport line of one direction of traffic (on one side of the street), m;

$B_{zh.\ zab}$ − the width of the zone of residential development in one direction of traffic (on one side of the street) within walking distance, m;

kn − coefficient of non-straightness of the pedestrian path to the line;

scheduled passenger transport;

$L^n\ pd$ − normative distance of pedestrian reach, m [1, 2].

Normative distances to stops of scheduled passenger transport [1, 2], m: in multi-apartment residential buildings ≤ 500 m; in medium-, low-rise and manor buildings ≤ 600 m.

Walking distance for one (direct) direction of passenger traffic:

$$L_{PD1} = \text{k n} * L_1 + L_2 \tag{1}$$

- (for pedestrians approaching the stop from the side of its location);

$$L_{PD2} = (\text{k n} * L_1 + B) + L_2 \tag{2}$$

- (for pedestrians approaching the stop from the opposite side of the street).

Taking into account that L_{PD1} and L_{PD2} take the maximum value, when a pedestrian goes to a stop from the edge of the zone of influence of the stop points, equating them to the normative radius of accessibility, taking into account that the maximum value for $L_2 = L_p/2$ (the pedestrian goes to the traffic line in the middle of the run), solving equation (1) and (2) relative to L_1, we obtain two values of the distances from the transport line to the limit of influence of stopping points:

$$L'_1 = L^n{}_{pd} / \text{kn} - L_P/2 \tag{3}$$

- (for the zone of influence of direct traffic directions − pedestrians do not cross the road);

$$L''_1 = L^n{}_{pd} / \text{kn} - L_P/2 - B \tag{4}$$

- (for the zone of influence of reverse traffic directions – pedestrians cross the road).

By combining the influence zones of the direct directions located on both sides of the road and adding the width of the road, superimposing the influence zones of the reverse directions one on top of each other, (the road falls into the influence zones of both reverse directions, therefore, in determining the width of the influence zone, it is taken into account once) we will get the width of the zone of influence of the stopping points of the forward and reverse directions of movement, where + B is for the forward direction, − B is for the reverse direction:

$$B_2 = 2\, L^n{}_{p\,d} \,/\, \text{kn} - L_P \pm B \tag{5}$$

In order for the condition of pedestrian reachability of stops from the boundary of the zone of influence of the transport line to be fulfilled, inequality (6) must be fulfilled:

$$B_2 = 2\, L^p{}_{p\,d} \,/\, \text{kn} - L_P \pm B \geq B_1 = 1000/\delta, \tag{6}$$

where: $+B$ is used in calculations of B_2 for the forward direction of movement; $-B$ - for the reverse.

Solving equation (6) with respect to $L^p{}_{p\,d}$, we obtain equation (7) for calculating the maximum approach distance to stops in the forward and reverse direction of traffic from the boundary of the zone of influence of the transport line:

$$L^p{}_{p\,d} = (1000/\delta \pm B)\ \text{kn}/2 + L_P/2 \tag{7}$$

where: $+B$ is used in calculations of $L^p pd$ of the reverse direction and $-B$ - forward.

Equations (6) and (7) have interconnected variables: k n; L_p and δ [1, 2], as well as B [5], the values of which are given in regulatory documents in the form of two extreme values, that is, their change is provided for in a certain interval, which allows maneuvering when planning urban areas without violating regulatory parameters.

After substituting the normative values of δ; L_P; In formula (7), by comparing the value of the maximum distance of the approach to the boundary of the zone of influence of the transport line L рпд with the normative distance of the approach Lнпд, it is possible to conclude whether the entire zone of influence of the transport line lies within the normative pedestrian distance.

Note: when calculating the maximum reachable distances from the border of the zone of influence of the transport line to the stopping points according to formula (7)) for a higher density δ, a longer distance between the stops L_p is taken.

The width of the carriageway of the road B [5]:

a) in the largest cities:

- city-wide value of regulated traffic – 12-24 m. (average value − 18 m);
- district value 6-18 m (average value − 12 m);

b) in big cities:

- city-wide value 6-18 m (average value − 12 m);
- district value 6-12 m (average value − 9 m);

c) in medium-sized cities:

- city-wide value 6-12 m (average value − 9 m);

d) local streets for all cities 6 m.

The coefficient of non-linearity of the pedestrian path kn = 1, 2 [24], which will be used in this study, requires additional research into the conditions of pedestrian movement within the residential group for different planning schemes for its determination.

By substituting into equation (7) instead of $L_{p\,д}$ the normative value of the approach $L_{н\,п\,д}$, we will obtain equation (8), by substituting the normative indicators into them, we will obtain the calculated indicators of the distances between stops to ensure the reach of stopping points from the boundary of the zone of influence of the transport line at the normative reach distance L^n pd :

$$L_P = 2\, L^n{}_{p\,d} - (1000/\delta \pm B)\ \text{kn}, \tag{8}$$

where: $+B$ is used for the forward direction of movement, $-B$ - for the reverse.

The width of the building zone within the zone of influence of the transport line of one direction of traffic (on one side of the street):

$$B_{z\,a\,b.} = (1000/\delta - B_{vul} - 12)/2. \qquad (9)$$

The width of the zone of residential development of one direction of traffic (on one side of the street) within the pedestrian reach according to the original data of normative documents [1; 2] is calculated by formula (10):

$$B_{zh.\,zab}. = L^n\,pd\,/\mathrm{kn} - Lp/2 \pm B/2 - B\,v\,u\,l\,/2 - 6, \qquad (10)$$

where: $+B/2$ is accepted in calculations for the forward direction of movement, $-B/2$ - for the reverse direction.

In the right part of the formula (9), the number 12 takes into account two distances between the red lines and the building, in the right part of the formula (10) − one distance [1].

Taking into account the slight difference in the width of the built-up zones of influence of stop points in the forward and reverse directions of traffic, as well as the purpose of the study, all calculations of the resource potential of the zone of influence of stop points are performed for the forward direction of traffic.

3 The results

Multivariate calculations of the parameters and resources of the zone of influence of the stopping points were performed using the limit parameters of the initial data for the larger ones, large, medium and small settlements. The obtained parameters of the zone of influence for individual groups of settlements are average and by zone: central, middle, peripheral.

Since the density of scheduled passenger transport for all groups of settlements and their zones [1] is accepted as 1.5-2.5 km/km^2, except for some cases in the central zone of the largest and coarse cities, where in some cases it is allowed by the norms of 3.5 km/km^2, the width of the zone of influence of the transport line is 667-400 m, except in some cases of the central zone of the largest and coarse settlements, where it can be 286 m.

The width of the zone of influence of the stopping points of the direct direction in the largest and coarse cities is average and in the middle zone is 500-450 m; in the central zone 700-600 m; peripheral − 400-350 m. The width of the zone of influence of the stopping points of the return direction, respectively: 440-390 m; 640-540 m; 340-290 m.

The width of the zone of influence of stop points in the direct direction in large and medium-sized cities is average, and in the middle zone it is: 345-245 m; in the central zone – 595-495 m; in the peripheral zone – 245-145 m. The average width of the zone of influence of the return stop points in the middle zone is 321-221 m; in the central zone – 571-471 m; peripheral zone −221-121 m.

The width of the zone of influence of stop points in the direct direction in small cities: in the central zone is 173-123 m (for an approach distance of 500 m), 256-206 m — (for an approach distance of 600 m); in the peripheral zone – 73-23 m (for an approach distance of 500 m); 156-106 m (for an approach distance of 600 m).

The maximum walking distance to the stopping points from the border of the zone of influence of the transport line with the normative distances between the stopping points is given in the Tables 1–3:

Table 1. The maximum walking distance to stopping points from the edge of the transport line's influence zone in the largest and coarse cities with normative distances between stops.

Maximum distances to stopping points, m	**average**	**central zone**	**middle zone**	**peripheral zone**
a) city-wide roads with regulated traffic	639-429 661-451	286-336 307-357	639-429 661-451	689-479 711-501
b) roads of regional importance	643-433 657-447	339-289 354-304	643-433 657-447	693-483 707-497
c) local roads	647-436 654-444	343-293 350-300	647-436 654-444	697-486 704-494
Note: in the numerator of the distance for passengers in the forward direction of travel, in the denominator − for the reverse direction				

Table 2. The maximum walking distance to the stops from the border of the zone of influence of the transport line in large and medium-sized cities with the standard distance between stops.

Maximum distances to stopping points, m	**average**	**central zone**	**middle zone**	**peripheral zone**
a) city-wide roads with regulated traffic	693-483 707-497	568-368 582-372	693-483 707-497	743-532 757-547
b) roads of regional importance	695-485 706-495	570-360 581-370	695-485 706-495	745-535 756-545
c) local roads	697-486 704-494	572-361 579-369	697-486 704-494	747-536 754-544
Note: in the numerator of the distance for passengers in the forward direction of travel, in the denominator − for the reverse direction				

Table 3. The maximum walking distance to stops from the border of the transport line's influence zone in small cities with the standard distance between stops.

Maximum distances to stopping points, m	**Central zone**	**Peripheral zone**
for passengers in the direct direction of traffic for passengers traveling in the opposite direction	536-647 543-654	636-747 643-754

The distances between stops at the standard walking distance to the boundary of the transport line's influence zone are given in Tables 4-9:

Table 4. Distances between stops at standard walking distance to the border of the zone of influence of the transport line in the largest and coarse cities in multi-apartment residential buildings, m.

Distances between stops, m	**Average**	**central zone**	**middle zone**	**peripheral zone**
Normative [1]	400-500	250-350	400-500	500-600
a) roads of city-wide importance	355-622 311-578	736 692	355-622 311-578	355-622 311-578

b) roads of district importance	347-614 319-586	728 700	347-614 319-586	347-614 319-586
Note: in the numerator of the distance for passengers in the forward direction of travel, in the denominator - for the reverse direction				

Table 5. Distances between stops at the normative distance of reach to the edge of the zone of influence of the transport line in the largest and coarse cities in medium-sized, low-rise and estate buildings.

Distances between stops, m	**average**	**central zone**	**middle zone**	**peripheral zone**
normative [1]	400-500	250-350	400-500	500-600
a) roads of city-wide importance with regulated traffic;	411-742 378-698	936 892	411-742 378-698	411-742 378-698
b) roads of district significance	547-734 519-786	928 900	547-734 519-786	547-734 519-786
c) local streets and roads	407-727 392-717	864 850	407-727 392-717	407-727 392-717
Note: in the numerator of the distance for passengers in the forward direction of travel, in the denominator − for the reverse direction				

Table 6. Distances between stops at the normative distance of reach to the border of the zone of influence of the transport line in large and medium-sized cities in multi-apartment residential buildings.

Distances between stops, m	**average**	**central zone**	**midle zone**	**peripheral zone**
normative [1]	500-600	250-350	500-600	600-700
a) roads of city-wide importance	347-614 319-506	347-614 319-506	347-614 319-506	347-614 319-506
b) roads of regional importance	344-611 322-509	344-611 322-509	344-611 322-509	344-611 322-509
c) local streets and roads	340-607 326-513	340-607 326-513	340-607 326-513	340-607 326-513
Note: in the numerator of the distance for passengers in the forward direction of travel, in the denominator − for the reverse direction				

Table 7. Distances between stops at the normative distance of reach to the border of the zone of influence of the transport line in large and medium-sized cities in medium-sized, low-rise and estate buildings.

Distances between stops, m	**average**	**central zone**	**middle zone**	**peripheral zone**
normative [1]	500 – 600	250 – 350	500 – 600	600 – 700

a) roads of city-wide importance with regulated traffic;	547 — 814 519 — 706	547 — 814 519 — 706	547 — 814 519 — 706	547 — 814 519 — 706
b) roads of regional importance	544 — 811 522 — 709	544 — 811 522 — 709	544 — 811 522 — 709	544 — 811 522 — 709
c) local streets and roads	540 — 807 526 — 713	540 — 807 526 — 713	540 — 807 526 — 713	540 — 807 526 — 713
Note: in the numerator of the distance for passengers in the forward direction of travel, in the denominator − for the reverse direction				

Table 8. Distances between stops at the normative distance of reach to the boundary of the zone of influence of the transport line in small cities in multi-apartment residential buildings.

Distances between stops, m	**central zone**	**peripheral zone**
normative [1]	500 – 600	700 –800
for the direct direction of travel for the reverse direction of movement	192 — 513 207 — 607	192 — 513 207 — 607

Table 9. Distances between stops at the normative distance of reach to the edge of the zone of influence of the transport line in small cities in medium-sized, low-rise and estate buildings.

Distances between stops, m	**central zone**	**heripheral zone**
regulatory	500 – 600	700 – 800
for the direct direction of travel for the reverse direction of movement	392— 713 407 — 807	392 — 713 407 — 807

The calculation of the area of the settlement territory of one run of the influence zone of the transport line is given in table 10.

Table 10. Parameters of the settlement territory of the one run of the influence zone of the transport line.

Indexes	**average**	**by zones**			**Groups populated points**
		central	average	peripheral	
The width of the zone of influence of the transport line, m.	667 − 400	286	667 – 400	667 − 400	the largest and coarse
Distance between stops [1], m	400 − 500	250 − 350	400 − 500	500 – 600	
Area of the territory, ha	20 – 26,7	7,2 – 10	20 – 26,7	24 – 33,4	
The width of the zone of influence of the transport line, m.	667 — 400	667 – 400	667 – 400	667 − 400	large and average

Distance between stops [1], m	500 — 600	250 – 350	500 – 600	600 – 700	
Area of the territory, ha	24 – 33,4	14 – 16,7	24 – 33,4	28 – 40	
The width of the zone of influence of the transport line, m.	–	667 – 400	–	667 – 400	are small
Distance between stops[1], m.	–	500 – 600	–	700 – 800	
Area of the territory, ha	–	24 – 33,4	–	32 – 46,7	
Note: for a larger width of the influence zone, a smaller distance between the stops is adopted and vice versa					

Tables 11-13 show: the width and built-up area of the influence zones of the transport line and stopping points for one transport run in the direct direction of movement. For the zones of influence of stopping points, this is the territory within the normative walking distance, that is, the area of residential construction.

Table 11. Parameters of the territories of residential development zones of influence of the transport line and stopping points of one direction of traffic of the largest and coarse cities.

Parameters	**average**	**central zone**	**middle zone**	**peripheral zone**
The width of the building zone within the zone of influence of the transport line (numerator) and the normative reach of stopping points (denominator) and: for streets of city-wide significance, m	318 — 154 195 —112	112 — 97 270 — 187	318 — 154 195 —112	318 — 154 145 — 98
the same for streets of district importance	323 — 169 197 – 130	117 — 112 272 – 205	323 — 169 197 – 130	323 — 169 165 — 97
the same for streets of local importance	335 — 177 207 – 141	130 — 120 282 – 215	335 — 177 207 – 141	335 — 177 167 — 91
The area of the land plot of one race ha: a) within the zone of influence of the transport line	7,7 – 13,4	3,4 — 3, 25	7, 7 — 13,4	9,24 – 16,75
b) within the regulatory reach distance of the stopping point	5,6 – 8,28	6,55 – 7,05	5,6 – 8,28	5,88 – 10

Table 12. Parameters of areas of residential development, zones of influence of transport lines and stopping points of one direction of traffic in large and medium-sized cities.

Parameters	**average**	**central zone**	**middle zone**	**peripheral zone**

The width of the building zone within the zone of influence of the transport line (numerator) and in the zone of normative pedestrian reach (denominator), m for streets of city-wide significance	154 — 303 77 — 142	154 — 303 167 — 202	154 – 303 77 — 142	154 – 303 (110 — 175)*
the same for streets of district importance	169 — 308 92 — 147	169 — 308 217 — 272	169 – 308 92 — 147	169 – 308 (125 — 180)*
the same for streets of local importance	177 –320 101 – 159	177 — 320 226 – 284	177 –320 101 – 159	177 – 320 (134 — 192) *
The area of the construction zone of one hectare: a) within the zone of influence of the transport line	7,7 — 19,2	3, 85 — 11,2	7,7 — 19,2	9, 24 — 22,4 9, 24 — 22,4
b) within the regulatory reach distance of the stopping point.	4,62 — 9,54	5,85 — 7,1	4,62 — 9,54	(7,7 — 11,5)*
*When Ln p d = 600 m — in parentheses				

Table 13. Parameters of the territories of residential development zones of influence of the transport line and stopping points of one direction of traffic in small cities.

Parameters	**central zone**	**peripheral zone**
The width of the zone of residential development within the zone of influence of the transport line (numerator) and in the zone of normative pedestrian reach (denominator) and: *When Ln p d = 600 m — in parentheses	177 —320 83 — 156	174 — 240 (74 — 140) *
The area of the building zone of one hectare: a) within the zone of influence of the transport line	8,85 — 19, 2	12, 4 — 25,6
b) within the standard reach distance of the stopping point: *When Ln p d = 600 m. — in parentheses	4,98 — 7,8	(5,18 — 11.2)*

Table 14 shows the parameters and calculation of the resource potential of the zones of influence of stopping points and transport lines: the total built-up area of one section of the transport line, the residential area of the zone of influence of one stopping point (buildings within walking distance of the stopping point), the maximum housing stock, the number of people in depending on the number of floors of the building, the number of sections of residential buildings that can be placed on the land plot of the zone of influence of the stop points.

Table 14. Resource potential of the zone of influence of stopping points of one direction of traffic.

Floor area of the building	The area of the land plot of the zone of influence of the stopping point, ha	Population density per hectare zones of influence of stopping points	The number of population in the territory of the zone of influence of the stopping point	The percentage of development of the land plot zone of influence stopping point	Area of residential construction of the land plot of the stop point, ha
1—3	4,55 – 13,4	330	1502 – 4422	50	2,28 – 6,7
	4,55 – 13,4	460	2093 – 6164	50	2,28 – 6,7
4	4,55 – 13,4	550	2503 – 7370	45	2,05 – 6,03
5	4,55 – 13,4	575	2616 – 7705	45	2,05 – 6,03
6	4,55 – 13,4	615	2798 – 8241	40	1,82 – 5,36
7	4,55 – 13,4	680	3094 – 9112	40	1,82 – 5,36
8	4,55 – 13,4	720	3276 – 9648	40	1,82 – 5,36
9	5,6 – 14,5	740	4144 – 10730	35	1.96 – 5.08
10	5,6 – 14,5	750	4200 – 10875	35	1.96 – 5.08
12	5,6 – 14,5	805	4508 – 11672	30	1,68 – 4,35
14	5,6 – 14,5	845	4732 – 12252	30	1,68 – 4,35
16	5,6 – 14,5	860	4816 – 12470	30	1,68 – 4,35
17 and above	5,6 – 14,5	950	5320 – 13775	30	1,68 – 4,35

Continuation of table 14.

Floor area of the building	Area of residential construction of the land plot of the stop point, ha	Building area for one typical residential section house, m 2	Number of typical sections residential buildings on land plot	The maximum density of the housing stock thousand m2 per 1 ha of the land plot of the influence zone	The maximum housing stock of the zone of influence of the stopping point for one direction of traffic
1 – 3	2,28 – 6,7	270	84 – 248	9,900	45,05 – 132,7
	2,28 – 6,7	270	84 – 248	12,87	58,56 – 172,5
4	2,05 – 6,03	270	76 – 223	14,85	67,57 – 199,0
5	2,05 – 6,03	270	76 – 223	17,64	80,26 – 236,4

6	1,82 – 5,36	270	67 – 198	19,59	89,14 – 262,5
7	1,82 – 5,36	270	67 – 198	19,93	90,68 – 267,1
8	1,82 – 5,36	270	67 – 198	21,00	95,55 – 281,4
9	1.96 – 5.08	270	76 – 188	22,80	127,7 – 330,6
10	1.96 – 5.08	270	76 – 188	24,60	137,8 – 356,7
12	1,68 – 4,35	270	62 – 161	24,65	138,0 – 357,4
14	1,68 – 4,35	270	62 – 161	24,75	138,6 – 358,9
16	1,68 – 4,35	270	62 – 161	24,85	139,2 – 360,3
17 and above	1,68 – 4,35	270	62 – 161	27,45	153,7 – 398,0

4 Discussion

Analysis of the calculation results showed the following.

1. The area of the territory of the settlement of the zone of influence of the transport line (Table 10) assigned to one run between the stopping points for most zones of settlements is from 16 to 40 hectares, with the exception of the central zone of the largest and largest cities, where it can reach only from 7 to 10 hectares

2. The ratio of the width of the zone of influence of the stopping points to the width of the zone of influence of the transport line varies, depending on the group of settlements, the zone of settlements, the density of transport lines, the distance between the stopping points and the standard walking distances to the stopping points within wide limits: from 2.45 (central zone of the largest cities, density of transport lines 3.5 km/km^2, distance between stops 250 m, walking distance to stops 500 m) to 0.14 (peripheral zone of small cities, density of transport lines 1.5 km/km^2 , the distance between the stops is 800 m, the walking distance to the stops is 600 m).

The large discrepancy between these indicators is due to the lack of balance between the density of transport lines, the width of streets, the distances between stopping points and the walking distances to them, which are given in [1, 2] as independent quantities, which leads to paradoxical consequences, when in the center of large and the largest cities due to a significant thickening of the density of transport lines with a simultaneous decrease in the distance between stopping points, the zone of influence of stopping points (pedestrian reach zone) can exceed almost 2.5 times the zone of influence of the transport line, which is impractical and will negatively affect the ecological condition in the city center.

On the contrary, in peripheral zones, where the ratio of the width of the zone of influence of the stopping points to the width of the zone of influence of the transport line is small, the standard walking distance may not be enough for residents of these zones to reach the stopping points, which will be discussed in more detail below.

As a conclusion to point 1, it is necessary to carry out a study in order to determine the optimal ratio between the density of transport lines, the width of streets, the distances between stopping points and the walking distances to them.

3. The ratio of the normative walking distance to the stopping points (500 m, except for the peripheral zone of small cities − 600 m) relative to the distance from the stopping points to the border of the zone of influence of the transport line (Tables 1-3) is

− for the middle zone of the largest and largest cities − 0.77-1.16, for the peripheral zone of these cities − 0.7-1.0; for the middle zone of large and medium-sized cities − 0.7-1.04, for the peripheral zone of these cities − 0.66-0.92; for the central zone of small cities − 0.77-0.93, for the peripheral zone of these cities − 0.8-0.94; thus, from the given ratios it follows that 20-30 percent of the zone of influence of the transport line, listed in the corresponding city zones, may be out of reach for the standard walking distance.

− for the central zone of the largest and largest cities, these ratios can be 1.4-1.75; for the central zone of large and medium-sized cities − 0.88-1.4, i.e., normative walking distances may exceed the necessary by 40%, which is due to the over-density of transport lines with a simultaneous decrease in the distances between stopping points, which are allowed by the norms [1], about the impracticality which and the need to conduct relevant research were mentioned in point 1.

4. A comparative analysis of the calculated distances between stops at the normative walking distance to the border of the zone of influence of the transport line (Tables 4-9) in relation to the normative distances between stops also showed an imbalance of normative indicators − the density of transport lines, distances between stops and walking distances. Thus, in the central zone of the largest and largest cities, the ratio of calculated distances to normative ones can reach from 2.43 to 3.74, that is, in this zone it is allegedly possible to increase the distance between stops from 850 to 936 m, which is usually unrealistic, so in this case it is necessary at the same time reduce the density of transport lines and increase the distance between stops, i.e. find their optimal ratio with a given pedestrian accessibility. In other zones, this ratio is also within wide limits from 0.24 (small cities, peripheral zone, normative distance between stops 800 m) to 1.97 (largest and largest cities, medium zone, normative distance between stops 400 m).

5. The area of the territory of the settlement in the zone of influence of the transport line is assigned to one run between the stopping points (Table 10) for most zones of settlements is from 16 to 40 hectares, with the exception of the central zone of the largest and largest cities, where it can reach only from 7 to 10 hectares.

6. The estimated width of buildings in the zone of influence of the transport line of one direction of traffic (tables 11-13), depending on the group and zone of settlements and the width of the streets, varies from 154 to 335 m, the estimated width of the zone of influence of stop points of one direction of traffic (within the standard walking distance) − from 74 to 284 m. Larger parameter values refer to the central and middle zones of cities, smaller values to peripheral zones. The ratio of the width of the built-up area of the zone of influence of stopping points to the width of the built-up area of the zone of influence of the transport line in most cases is ~ 0.5-0.8, with the exception of the central zone of the largest and largest cities, where a density of transport lines of 3.5 km/km^2 and a distance of between stops 250-350 m and where this ratio can reach from 1.0 to 2.4, which once again indicates the need to balance regulatory indicators.

7. The estimated area of the settlement of one section of the zone of influence of the transport line is (Table 11-13) ~20-50 hectares, which can be compared with the area of the microdistrict (15-60 hectares) [Article 1. 17]. The exception is the central zone of the largest and largest settlements, where this indicator is ~10 ha.

8. As for the area of the land plot of the zone of influence of the transport line that remains for development (Tables 11-13), the calculation showed that it can have dimensions from 3.4 to 25.6 hectares, and for the area of the land plot within the limits of the influence zone of stopping points (within the standard walking distance) − from 4.6 to 11.5 hectares. The ratio of the area of the second plot of land to the first in most cases is ~0.7-0.5, except for the

central zone of the largest and largest settlements, where this indicator reaches ~2.0, and the central zone of large and medium-sized cities, where it is ~1. 0. The given calculations also lead to the conclusion of the imbalance of the normative indicators of the density of transport lines, distances between stops and pedestrian distances and street widths and the need to coordinate them with the necessary areas of land plots under development, because the transport line is intended to serve the population living in this territory and using the corresponding stops, and the formation of passenger flows takes place in accordance with the area of these territories and the number of their population.

9. The analysis of the resource potential of the zone of influence of the stopping point of one direction of public transport (Table 14) indicates the following.

The estimated population in the area affected by the stop point of one direction of public transport, depending on the number of floors of the building, is from 1,502 to 13,775 people, the maximum estimated housing stock is from 45,000 m^2 to 398,000 m^2. The estimated number of typical sections of residential buildings that can be placed on a plot of land in the zone of influence of a stop point of one direction of public transport is from 84 to 248, from which it is possible to form, taking into account intermediate and end sections, from 8 to 24 ten-section buildings, i.e. approximately from 2 to 6 residential groups.

5 Conclusions

Territories of settlements in the zone of influence of stopping points occupy an important place in the planning structure and vital activities of settlements due to their significant resource potential − territory, population, housing stock, as well as the close relationship of their structural parameters with the parameters of the transport infrastructure, which indicates the need to consider them as a whole. The estimated population of the zone of influence of the stop makes it possible to estimate the passenger flow of public transport even at the project stage of city territory planning. Of course, this requires separate research and assumptions.

The density of public transport lines, the distance between stops, the walking distance to stops, the width of streets and roads must be balanced with each other when determining the built-up area of the zones of influence of public transport lines and stop points, for which it is necessary to conduct additional theoretical studies, taking the above-mentioned as initial data building area, or the population of the area of influence of the settlement.

The listed parameters in the range of min − max should be divided into a number of intermediate values in order to better balance them and use modular design.

In the studied sources of information, there is no substantiated value of the coefficient of non-linearity of the pedestrian path to the public transport line within the residential group, so it is also necessary to conduct empirical studies of residential groups of different planning structures in order to determine this coefficient. When designing residential groups, pay attention not only to the conditions of insolation and ventilation, but also to the maximum reduction of the pedestrian path to the bus stop.

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