

Article

Assessment of Accessibility of Public Transport by Using Temporal and Spatial Analysis

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Abstract: The development of sustainable transport is a priority in cities. It should aim to increase the number of trips made by public transport while minimizing social costs and the negative impact on the environment. The intensive development of cities from industrial to service-oriented and the phenomenon of suburbanization require changes in public transport services. However, often, operators do not change existing lines and stops or timetables justifying it with passenger habits. This approach may cause a discrepancy between the accessibility of public transport services and the demand for these services. Therefore, planning and improving the public transport system should be based on careful analyses. There are various approaches to this problem. The article presents a method to assess accessibility of public transport services using spatial and temporal analysis. The proposed method is based on dividing the area into basic fields and then, using appropriately selected measures, each field is assessed in terms of both the current level of accessibility of public transport services and the potential transport demand. A comparative analysis with the use of spatial tools indicates the degree of matching of these values and enables the identification of areas (basic fields) in which improvement of public transport services is required. For the proposed method, a case study was carried out for the city of Czeladź, located in Metropolis GZM in the southern part of Poland. The method can support decision making to improve the current public transport system.

Keywords: public transport; GIS-based method; spatial analysis; GIS; systemic approach; sustainable mobility; transport demand; accessibility; sustainability



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1. Introduction

Research shows that satisfaction with the living conditions of residents of an area is related to the quality of travel within that area [1]. Unfortunately, mobility in large urban metropolitan areas faces many problems. These include congestion, noise, and air pollution, and the problem of parking spaces availability [2,3]. Most of these problems are due to the growing number of individual transport users. Currently, individual households often have more than one private car [4]. The way to solve these problems is to change the way urban users think about public transport and encourage them to use it more frequently [5]. These problems can be solved through a national or city transport policy, as described in the documents that establish the Sustainable Development Goals [6]. Sustainable urban mobility plans should also be developed for the affected areas [7].

To convince users to switch to public transport, the needs and expectations of residents must be met [8–11]. This is especially important in a post-epidemic situation where the share of public transport travel has clearly decreased [12–15]. The use of public transport is improved by ensuring a modern fleet with vehicles that have environmentally friendly engines and that meet the quality expectations of passengers, such as air conditioning, smartphone chargers, free Wi-Fi, and accurate route information [16,17]. Another critical aspect in the increase in public transport trips is accessibility [18,19].

The dynamic development of urban areas and the phenomenon of suburbanization are forcing public transport operators to introduce changes to ensure accessibility to public transport [20]. For this purpose, existing routes are modified, new routes are introduced, and new stops are created [21]. These actions are necessary to ensure greater access to public transport, which will ensure the demand for transport services and reduce the phenomenon of exclusion of transport [22]. These solutions are consistent with the idea of sustainable development and trends in environmental protection [23]. Accessibility to public transport services increases mobility and may also be a factor in accelerating urban development [24]. A problem with these changes in the management of public transport is how assessment of accessibility is carried out in a given area. Different approaches to the problem can be found in the literature, including survey methods or the use of GIS tools with bus stop access isochrones [25–29]. Depending on the purpose, these approaches may only allow the assessment of a new bus stop location. To analyze the functioning of the entire public transport system in a given area, a systematic approach is required that takes other factors into account.

This article presents a method to assess the accessibility of public transport in urban areas using measures to estimate the degree of compliance of the accessibility of the public transport service with the potential demand for transport. This method includes consideration of the spatial and temporal aspects of the analysis and results in the designation of areas with insufficient access to public transport. The proposed method involves dividing the area into smaller and homogeneous parts to be able to observe changes in accessibility within the area being analyzed.

The article is divided into six parts. Section 2 presents a review of the literature that presents the complexity of the concept of accessibility to public transport and the different approaches to its spatial and temporal assessment. This section also includes a reference to the use of spatial analysis tools to assess accessibility. Section 3 presents a research method to assess the accessibility of public transport using measures both in terms of potential demand for public transport and accessibility of public transport service. Statistical measures were used in the comparative analysis. An example of the implementation of the proposed method is presented in the next section. The city of Czeladź located in Poland in Metropolis GZM, a large metropolitan area in the Silesian Voivodeship was selected for analysis. The discussion and conclusions are presented accordingly in Sections 5 and 6.

2. Related Literature

In order to choose the method for assessing the accessibility of public transport services, a literature review was carried out in search of issues related to accessibility, considering temporal and spatial aspects.

The concept of public transport is defined as generally available regular passenger transport provided at specified intervals and along a specified route, routes, or network [30]. Public transport must fulfil many requirements and meet passengers' expectations in terms of directness, frequency, accessibility, reliability, low cost, speed, punctuality, regularity, accurate information, comfort, level of crowding in vehicle, cleaning, connections, environment, courtesy of staff, safety, and security [31,32]. It is also important to consider the specific needs of different groups of passengers, e.g., elderly people [33]. This article concerns accessibility, which is an important factor in increasing the share of public transport. The study of accessibility allows identification of areas that need improvement.

Accessibility is widely described in the literature but does not have a single definition. Access to transport has been defined as the ability to use transport services and reach certain destinations with them [34], while accessibility to public transport is defined as the ease of access to public transport facilities and the ease of reaching destinations with that transport.

The literature distinguishes two basic components of accessibility: the transport component and the land use component, and two additional components: time and in-

dividual [8]. The transport component reflects the ease of travel between two points in space, while the land use component is the attractiveness of a given location as a destination in the transport system [35]. The temporal component defines availability over 24 h, as well as when certain activities are performed, while the individual component focuses on individual characteristics and needs of passengers [36]. All these components are interrelated.

Numerous methods for measuring transport accessibility can be found in the literature [37–40]. Rosik [41] suggests distinguishing five main methods of measuring accessibility, that is:

- measured by infrastructure equipment—the use of infrastructure equipment indicators,
- measured by distance—the distance (physical, time, economic) between the source and destination,
- cumulative (isochronous)—an estimate of the set of destinations available at a given time, cost, or effort,
- potential—the possibility of interaction between a starting point of travel and a set of destinations,
- personified—related to the individual socioeconomic characteristics of the road user.

For many years, the potential model has been one of the most popular research methods for accessibility analyses [42,43]. For this model, the attractiveness of a destination increases with its size and decreases as the physical, temporal, or economic distance increases [44–46].

Śleszyński [47] describes six attributes of transport accessibility: spatial, communicational, temporal, sociocultural, economic, and purpose. Among them, the most important are temporal and spatial, which are described in the following subsections [48].

2.1. The Temporal Aspect of Accessibility of Public Transport

Temporal accessibility can refer to both the time required to reach a bus stop from the starting point and the time required to travel between two bus stops using public transport [49].

When studying temporal accessibility, three groups of accessibility measures are most used:

- the frequency of departures of public transport vehicles, usually defined by the number of trips in the period examined [50],
- accessibility to a means of transport, characterized as the time required to walk to a stop [51],
- the time needed to travel by means of transport, characterized as the time needed to travel by means of transport to the destination [34].

The literature lists four categories of time accessibility that affect the measurement of time distance [52]:

- gross journey time—characterized as the total travel time between two door-to-door points,
- net journey time—characterized as the travel time between boarding the first vehicle and leaving the last vehicle,
- gross transport time—defined as the time required to travel between two points in a transport system, excluding time spent waiting to transfer,
- net transport time—characterized as the time necessary to travel between two points in a transport system, excluding traffic delays and technical delays.

The most commonly used tool in time accessibility studies are isochrones, lines of equal time distance from a given point [53]. An ideal isochrone takes the shape of a circle, but due to the shape and the layout of the land and obstacles that exist, the actual isochrone has a more irregular shape [54,55].

2.2. The Spatial Aspect of Accessibility of Public Transport

Spatial accessibility is related to the distance covered in a journey and is most often determined by access to the public transport infrastructure in a given area [56]. The concept of spatial accessibility can be identified with transport accessibility under certain conditions, but usually functions as a narrower concept.

When studying spatial accessibility, the most used measure is the availability of linear or point infrastructure defined for a given area [27,57]. Measures of accessibility of the linear infrastructure include indicators of the density of the transport network in relation to the number of people [58]. For point infrastructure, the density of bus stops is analyzed, which can be determined geographically and demographically, as well as the catchment area of the stop, which is determined by the surface area and the walking distance to or from the stop [59,60]. The maximum walking distances most accepted in Poland are 300 m in the city centers and 800 to 1000 m in areas with single-family housing [4].

Some authors pay attention to the complementarity of spatial and temporal accessibility, indicating that each type of accessibility concerns movement along a certain distance at a certain time [61,62].

2.3. Assessment of Accessibility of Public Transport Using Spatial Analysis

The main goal of the accessibility analysis we describe with temporal and spatial aspects is to improve public transport [63,64]. Improving the accessibility quality of public transport involves many different factors. The author in [65] used spatial analysis to evaluate the connectivity between routes, which is related to the distances between the transit points. Another method used to assess public transport accessibility is modal split modeling, which allows the identification of optimal sites for charging infrastructure for electric vehicles [66]. This article focuses on improving the public transport offer by evaluating the opportunities for passengers to use it. This problem is approached using spatial analysis asking which combination of parameters in spatial analysis gives the best assessment of public transport.

GIS-based methods are useful tools to assess accessibility to public transport [67,68]. This can be done at different levels, e.g., local, and global transport. In [69], the authors assessed public transport in tourist destinations in the Cambrils region of Spain. The analysis was based on five indicators, which described the number of stops per 1000 of population, population living less than 200 m from a bus stop, population living less than 200 m from a multimodal stop, connectivity, and population living less than 500 m from an intercity bus stop. Another study [70] was carried out for the Metropolitan City of Rome in Italy. The authors used an analysis based on graph theory. Another potential data source for the assessment of public transport are social media applications [71]. The authors in [72] used GTFS files to assess the public transport offer. This method was based on temporal considerations in accessibility studies.

In summarizing the literature review, it can be stated that the issue of compliance between the public transport offer and potential transport demand has not been explored in depth. Accessibility analyses focus mainly on spatial measures and rarely consider the time factor. Thus, the authors' contribution is presented below:

- we propose a new research method to assess accessibility of public transport services using spatial and temporal analysis,
- the method allows effective analysis based on easily accessible data, because it is based on spatial analyses with the land use measures to assess potential transport demand,
- our approach may be treated as the first stage of further in-depth analyses for the fields where significant non-compliance has been identified in this respect.

3. Research Method

The main assumption of the method was to develop a universal approach that, based on easily available data, would support the process of assessing the compliance of the level of public transport offer with the roughly estimated transport demand. Spatial and

temporal measures were used for this purpose. The proposed method consists of several main parts. The general scheme of the adopted method is shown in Figure 1. This diagram presents the subsequent stages of the analysis.

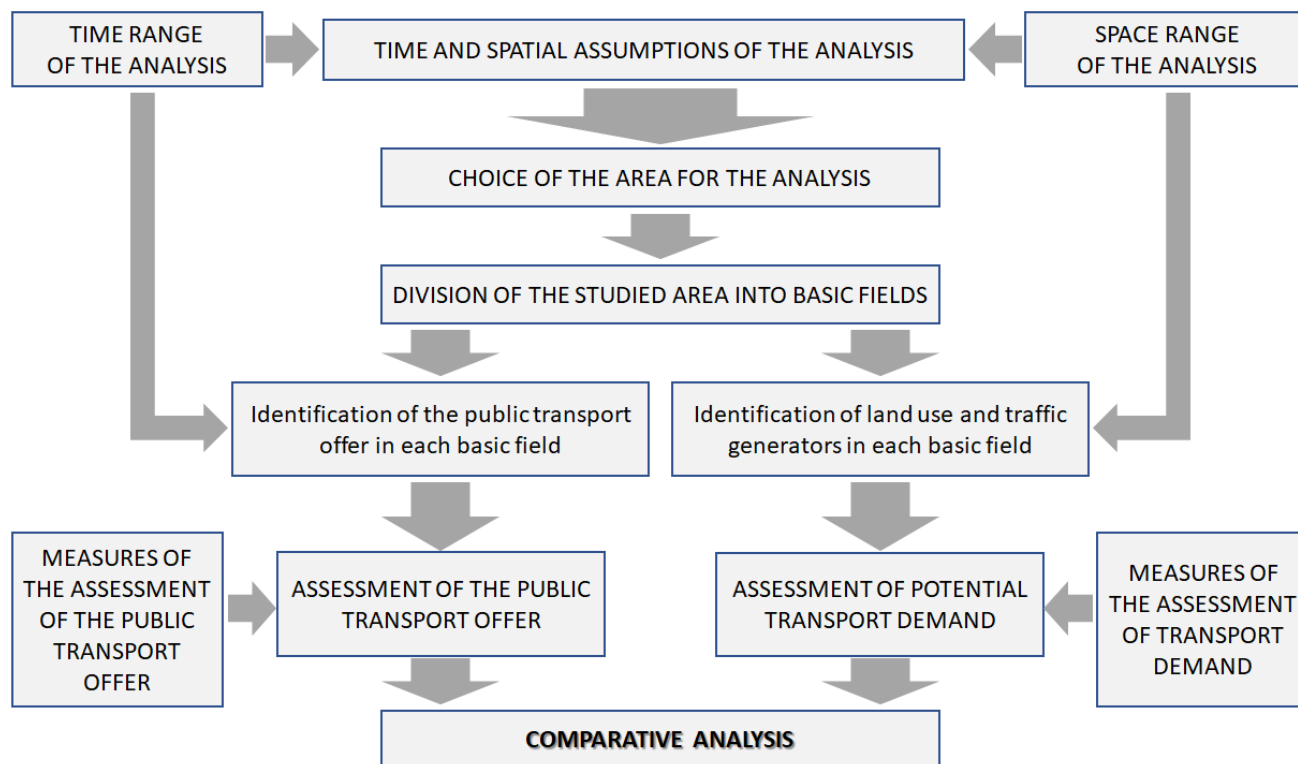


Figure 1. The general diagram of the research method.

Before starting the research, assumptions must be made about the temporal and spatial scope of the analysis. The following general assumptions were made for the conducted research:

- regarding the assessment of the accessibility of public transport service:
 - the analysis covered only working days,
 - the working day has been divided into five time periods, that is:
 - period 1—from 4 a.m. to 6 a.m.—the period before the morning peak,
 - period 2—from 6 a.m. to 9 a.m.—the morning rush period,
 - period 3—from 9 a.m. to 2 p.m.—the inter-peak period,
 - period 4—from 2 p.m. to 5 p.m.—the afternoon rush period,
 - period 5—from 5 p.m. to 11 p.m.—the period after the afternoon rush,
- regarding the assessment of potential transport demand:
 - traffic generators are divided into 5 categories, i.e.,:
 - category 1—single-family housing,
 - category 2—low multi-family housing,
 - category 3—high multi-family housing,
 - category 4—workplaces,
 - category 5—schools.

An important step in the adopted research method is the selection of the area of analysis and its division into basic fields. This requires defining the rules for delimiting the area and its surroundings. There are many methods to delimit an area [73]. One of them assumes that the boundaries of the studied area can be determined based on the administrative boundaries of a territorial unit, i.e., city, poviát, region, or voivodship. In

the proposed approach, the city boundaries were assumed to be the boundaries of the area studied [74].

The choice of how to divide the space depends primarily on the purpose of the research. Generally, there are two basic models of geographical space division, closely related to spatial data models: vector and raster models. In the case of vector models, the area of analysis is divided into territorial units of irregular shape, created based on administrative, structural, technical, or functional criteria. This division is used mainly in the construction of transport models [74]. In turn, raster models are based on regular-shaped basic fields, which constitute elementary spatial units to which a set of attributes is assigned. In this case, the values of the attributes cover the entire geographical space studied. Such a division requires imposing a regular grid (e.g., triangular, square, hexagonal, etc.) on the analyzed area. In the proposed method, it was assumed that the examined area of the city was divided into a regular grid with square-shaped fields [75].

When dividing the studied area into basic fields of regular shape and adopting administrative boundaries as the boundaries of the area, special attention should be paid to the fields located on the boundaries of the area. Before proceeding to analyses, it is necessary to decide how such basic fields will be treated in the analysis. There are three possible approaches:

- exclusion of fields located on the administrative boundaries of the area under study,
- inclusion of entire fields located on the administrative boundaries of the area under study,
- analysis of fields located on the administrative boundaries of the area only in the part that belongs to the area; it requires cutting the fields to the administrative boundaries of the area and appropriate recalculation of the attributes of these fields, considering their different area in relation to other fields, the area of which is entirely within the boundaries of the area under study.

In the proposed method, the third of the above-mentioned approaches was chosen. The applied method assumes that the analysis will be carried out only for the areas of basic fields within the administrative boundaries of the city.

Based on the predetermined spatial and temporal range of the analyses, it is necessary to identify the public transport offer, land use, and traffic generators in each basic field. They constitute input data to determine the measures of assessment of the accessibility of public transport, as well as the measures of assessment of the potential demand for transport.

The final stage of the analyses is the calculation of the value for each of the selected measures and the estimation of its level. This enables a comparative analysis related to accessibility of public transport and the potential demand for public transport services in each basic field and the determination of fields with large discrepancies in this respect.

3.1. Assessment of the Potential Transport Demand

The proposed approach assumes that the level of potential transport demand in each basic field depends on the land use and the traffic generators located in this field. Moreover, assuming a homogeneous share of public transport trips in entire city, it can be assumed that the level of potential demand for public transport services in each basic field corresponds to the estimated number of people living in a given field and/or using objects (i.e., traffic generators) located in this field. Therefore, the potential transport demand in each basic field was estimated using the attributes of the traffic generators in the categories determined.

Moreover, due to the previously adopted assumption concerning the basic fields located on the city borders, in the assessment of the potential transport demand, instead of the number of people using the traffic generators located in the basic fields, it is more advantageous to consider the density measures of these people.

Based on the above assumptions, measures to assess the potential demand for public transport services were developed for individual basic fields.

The density of people living in single-family housing (category 1 of traffic generators) in the i -th basic field was determined from the formula:

$$Z_i(1) = \frac{a_{SF} \cdot SF_i}{A_i}, \quad \left[\text{persons/km}^2 \right] \quad (1)$$

where:

a_{SF} —average number of people living in one single-family house (persons),

SF_i —the number of single-family houses in the i -th basic field,

A_i —the area of the i -th basic field (km^2).

The density of the population living in low multi-family housing (category 2 of traffic generators) in the i -th basic field can be determined from the general formula:

$$Z_i(2) = \frac{a_{MF} \cdot b_{MF} \cdot K_{LMF} \cdot LMF_i}{A_i}, \quad \left[\text{persons/km}^2 \right] \quad (2)$$

where:

a_{MF} —average number of people per 1 m^2 of multi-family housing area (persons/ m^2),

b_{MF} —share of the area of multi-family buildings intended for housing (–),

K_{LMF} —the coefficient determining the average number of stories of low multi-family buildings,

LMF_i —the total area of low multi-family buildings in the i -th basic field (m^2).

The density of the population living in high multi-family housing (category 3 of traffic generators) in the i -th basic field can be determined from the general formula:

$$Z_i(3) = \frac{a_{MF} \cdot b_{MF} \cdot K_{HMF} \cdot HMF_i}{A_i}, \quad \left[\text{persons/km}^2 \right] \quad (3)$$

where:

K_{HMF} —the coefficient determining the average number of stories of high multi-family buildings,

HMF_i —the total area of high multi-family buildings in the i -th basic field (m^2).

The density of employees at workplaces (category 4 of traffic generators) in the i -th basic field was estimated from the formula:

$$Z_i(4) = \frac{a_{WP} \cdot WP_i}{A_i}, \quad \left[\text{persons/km}^2 \right] \quad (4)$$

where:

a_{WP} —average number of employees per 1 m^2 of workplaces area (persons/ m^2),

WP_i —the total area of buildings being workplaces in the i -th basic field (m^2).

The density of students attending secondary and high schools (category 5 of traffic generators) in the i -th basic field was determined according to the formula:

$$Z_i(5) = \frac{SS_i + HS_i}{A_i}, \quad \left[\text{persons/km}^2 \right] \quad (5)$$

where:

SS_i —the total number of students attending all secondary schools located in the i -th basic field (persons),

HS_i —the total number of students attending all high schools located in the i -th basic field (persons).

The assessment of the potential transport demand for each i -th basic field was determined based on a measure representing the sum of the population density estimated for each of the five categories of traffic generators, according to the formula:

$$Total_Z_i = \sum_{c=1}^5 Z_i(c), \quad \left[\text{persons/km}^2 \right] \quad (6)$$

where:

$Z_i(c)$ —density of people in the i -th basic field determined for the c -th category of traffic generators.

3.2. Assessment of Accessibility of Public Transport Service

It was assumed that each public transport stop consists of a particular number of public transport stop stations. This concept has been presented for an example bus stop in Figure 2.

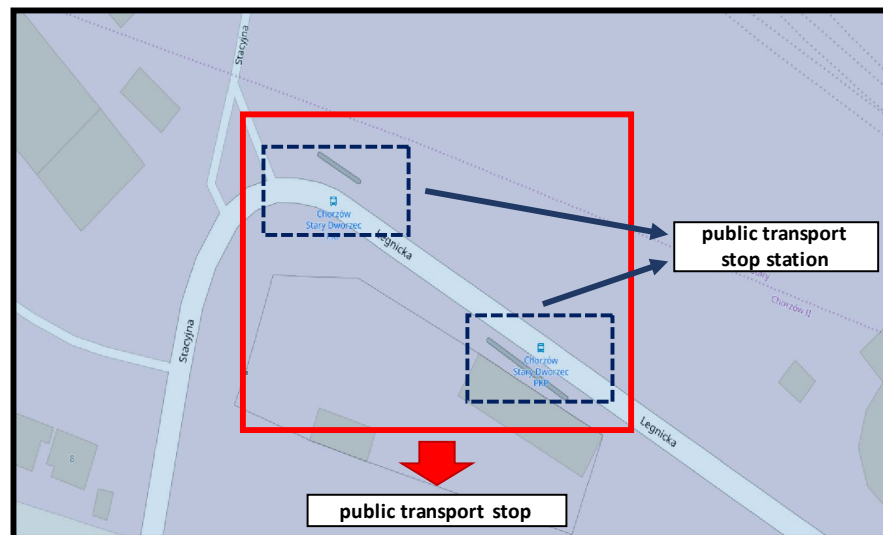


Figure 2. Concept of a public transport stop and public transport stop stations.

Depending on the purpose and scope of the study, as well as the selected research method, numerous measures of assessment of the accessibility of public transport can be distinguished in research on transport accessibility. For the conducted analysis, four measures were selected which were defined for each basic field, that is:

- density of stop stations,
- the average number of lines serving the stops,
- the average time interval between successive departures of public transport vehicles from the stop station at different times during the day,
- the range of direct impact of the basic field by public transport.

The density of stop stations in the i -th basic field is defined as the ratio of the number of stations in the basic field to the area of this field in the city area and is determined using the formula:

$$D_i = \frac{SSN_i}{A_i}, \quad [\text{stop stations}/\text{km}^2] \quad (7)$$

where:

SSN_i —the number of stop stations in the i -th basic field.

The average number of public transport lines that serve the single stop station located in the i -th basic field was determined according to the formula:

$$L_i = \frac{\sum_j SSL_{ji}}{SSN_i}, \quad [\text{lines}/\text{stop station}] \quad (8)$$

where:

SSL_{ji} —the number of lines serving the j -th stop station in the i -th basic field.

The average time interval between successive departures of public transport vehicles from the stop station in the i -th basic field is determined for each of the five time periods. For a single t -th period, it is calculated according to the formula:

$$TI_i(t) = \frac{SSN_i \cdot H(t)}{\sum_j \sum_l C_{lji}(t)}, \quad [\text{minutes}] \quad (9)$$

where:

$H(t)$ —length of the t -th period (minutes),

$C_{lji}(t)$ —number of courses of the l -th line serving the j -th stop station in the i -th basic field in the t -th period.

The measure of the assessment of the range of direct impact of the analyzed basic field is the number of basic fields associated with this field by public transport lines. Practically, for the analysis of accessibility of public transport, the measure is determined as the number of basic fields with at least one stop station connected directly to the analyzed field by the same line (regardless of the direction of the line), which also serve at least one station in the field under study. This measure was determined from the following formula:

$$BF_i = \sum_k R_{ik}, \quad i \neq k \quad [\text{basic fields}] \quad (10)$$

where:

R_{ik} —the binary variable.

The binary variable R_{ik} is calculated for $i \neq k$ and reaches the value 1, if at least one line serving a stop station in the i -th basic field also serves at least one stop station in the k -th field, and the value 0 in the absence of such connection.

3.3. Comparative Analysis

The main assumption of the analysis is to compare the levels of measures of assessment of the accessibility of public transport service with the levels of estimated potential transport demand for each basic field. It was assumed that the number of levels for each of the measures is the same and each of the level corresponds to the defined ranges of values determined individually for each measure.

The analysis used two measures of the degree of matching the accessibility of the public transport service to the potential demand for transport. By marking in the i -th basic field the level of potential transport demand as $ML(Total_Z_i)$ and the levels of individual measures for assessing the accessibility of public transport, respectively, as $ML(D_i)$, $ML(L_i)$, $ML(TI_i(t))$, and $ML(BF_i)$, the measures of matching these levels can be determined from the following dependencies:

- the absolute difference between the levels of individual measures for assessing the accessibility of public transport and the level of potential transport demand, calculated according to the formulas:

$$ADL(D_i) = ML(D_i) - ML(Total_Z_i), \quad (11)$$

$$ADL(L_i) = ML(L_i) - ML(Total_Z_i), \quad (12)$$

$$ADL(TI_i(t)) = ML(TI_i(t)) - ML(Total_Z_i), \quad (13)$$

$$ADL(BF_i) = ML(BF_i) - ML(Total_Z_i), \quad (14)$$

- the absolute difference between the level of aggregate measure for assessing the accessibility of public transport service and the level of potential transport demand, calculated according to the formula:

$$AADL(i, t) = AML(i, t) - ML(Total_Z_i) \quad (15)$$

where the level of the aggregate measure $AML(i, t)$ is calculated as weighted average of levels of individual measures for assessing the accessibility of public transport, i.e.:

$$AML(i, t) = w_1 \cdot ML(D_i) + w_2 \cdot ML(L_i) + w_3 \cdot ML(TI_i(t)) + w_4 \cdot ML(BF_i) \quad (16)$$

with w_1, w_2, w_3 , and w_4 denoting weights for individual measures and meeting the following assumptions:

$$0 \leq w_u \leq 1 \quad \wedge \quad \sum_{u=1}^4 w_u = 1 \quad (17)$$

As a result, absolute measures were obtained to assess the degree of compliance of the accessibility of public transport services with the potential transport demand in each basic field. The values of these measures are estimated for both individual and aggregated data, with the values of the measures $ADL(TI_i(t))$ and $AADL(i, t)$ being determined for specific five periods of the day. According to the proposed method, the values of measures $ADL(D_i)$, $ADL(L_i)$, $ADL(TI_i(t))$, $ADL(BF_i)$ (Formulas (11)–(14)), and $AADL(i, t)$ (formula (15)) that are close to 0 represent a high level of compliance between the public transport offer and demand in a basic field. The value of 0 means that the public transport offer precisely meets the demand. The largest positive or negative values correspond to the highest levels of non-compliance, with the positive values indicating an overestimation of the public transport offer concerning the potential demand and the negative values—an underestimation.

4. Case study

4.1. Research Area

The spatial and temporal analysis of the accessibility of the public transport service has been applied to a city of Czeladź in Poland. The chosen city is in the Upper Silesia region, in Górnośląsko-Zagłębiowska Metropolis (GZM), a large metropolitan area in the Silesian Voivodeship, consisting of 41 municipalities. The metropolitan area is inhabited by more than 2.3 million people and occupies an area of approximately 2550 km² [76]. The location of Czeladź on the background of Silesian Voivodeship and Metropolis GZM is presented in Figure 3. The city of Czeladź is bordered by four cities with poviats rights: Siemianowice Śląskie, Katowice, Sosnowiec, and Będzin.

The city area is 16.38 km². In terms of area, Czeladź ranks seventh among the communes of the Będzin poviats and 38th among the communes of the Metropolis GZM. According to the data from the Central Statistical Office, as of 30 June 2020, the city was inhabited by 31,287 people [76]. Most of the inhabitants are people of working age—57.16% of all inhabitants. People of pre-working age constitute 15.23%, and people of post-working age constitute 27.61%. In terms of population, Czeladź ranks 2nd among the communes of Będzin poviats and 18th among the communes of the GZM. The population density of Czeladź is 1910 people/km², which is the highest value among communes in the Będzin poviats and the seventh in the GZM.

Although Czeladź is one of the smallest communes in Metropolis GZM, it is a commune with a high population density and relatively densely built-up buildings. The city is strongly connected with other cities of the Metropolis, especially with Będzin, Sosnowiec, and Katowice. In recent years, Czeladź has become more and more popular among investors. Due to the good accessibility of the road network, the economic zone is being developed in the city, providing more jobs. Development is also taking place in the field of residential buildings, development investments are in the city, mainly in the form of single-family housing estates.

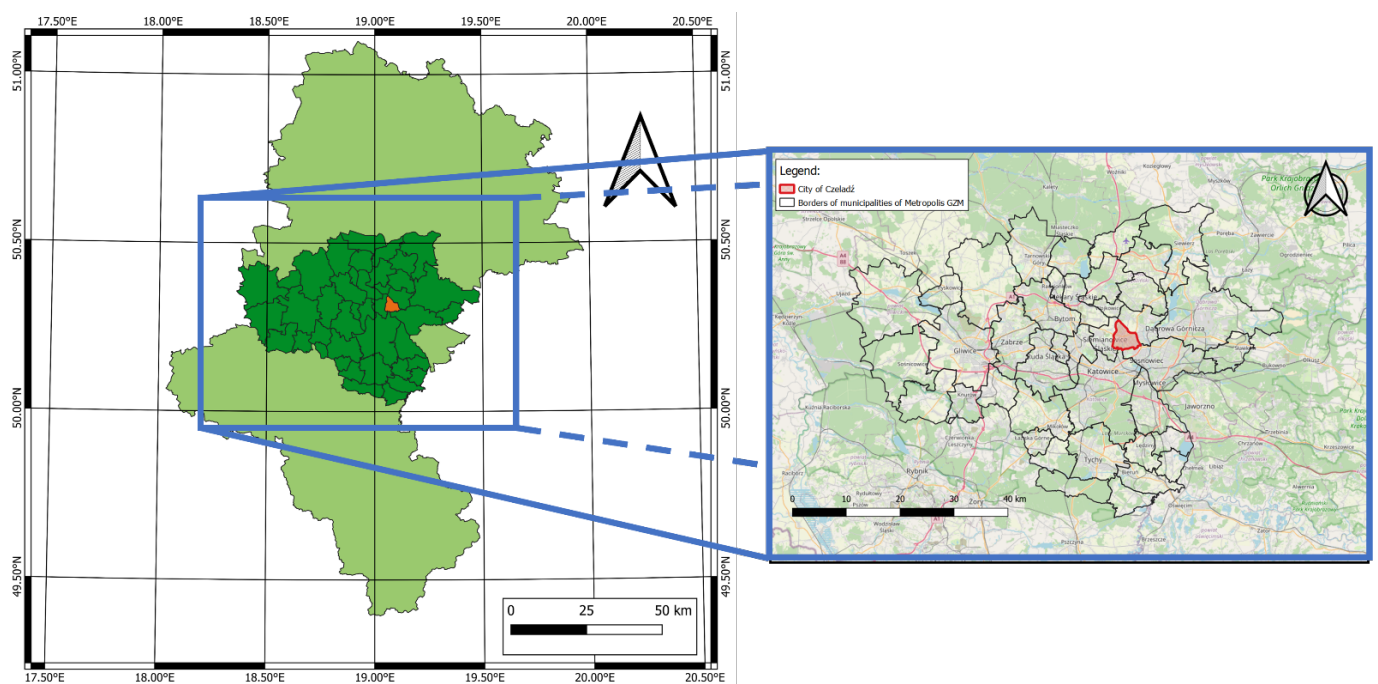


Figure 3. The location of Czeladź on the background of Silesian Voivodeship and Metropolis GZM.

For the purposes of the analysis, the city was divided into regular basic fields. The fields on the city border have been cut to its administrative boundaries. As a result of the division, 45 basic fields have been obtained, which are presented in Figure 4.

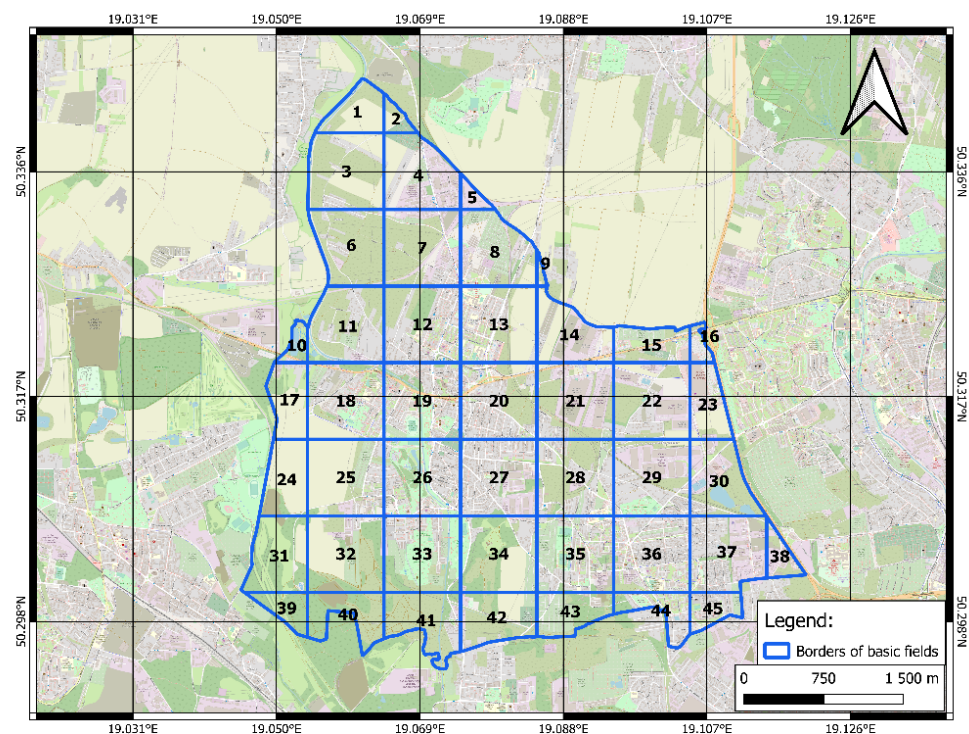


Figure 4. Division of Czeladź into basic fields.

Due to the irregular location of the outer borders of the city, not all basic fields are entirely located within the city area. For the area analyzed, 18 basic fields are entirely located within the city boundaries. The remaining fields are partially located within the city, ranging from 4% to 98% of the field area.

4.2. Results of the Assessment of the Potential Transport Demand

The spatial and temporal analysis requires the acquisition of data about land use and built environment in the analyzed area. The main objects that generate the potential demand for transport are residential buildings, workplaces, and schools. The location of specific built environment objects divided into five categories in basic fields in the city is presented in Figure 5.

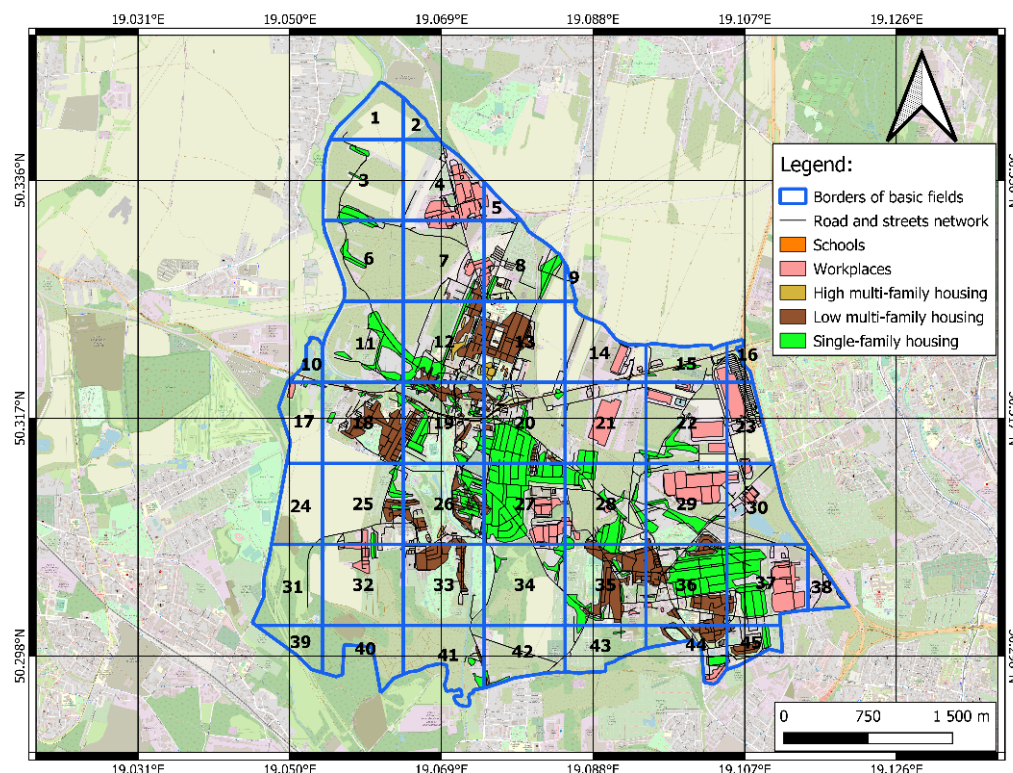


Figure 5. Built environment objects in the city of Czeladź.

The residential buildings in Czeladź are highly diversified and are not uniformly distributed throughout the city. The largest groups of buildings are located in the central part and in the west and south-east of the city. Among the buildings, one can distinguish single-family housing, as well as low and high multi-family housing.

Single-family housing is located in various parts of the city, both in the form of single-family housing estates and in the form of individual buildings. In total, such buildings are located in 30 of 45 basic fields. The largest area of single-family housing is in field No. 27 (55% of the field area) and in fields Nos. 20, 36, and 37 (30–35%).

Low multi-family housing in a city most often occurs as a larger group of residential buildings. It is located within the area of 21 basic fields. The largest share of low-rise multi-family buildings occurs in field No. 35 (29% of the field area) and in fields Nos. 13, 18, 36, and 44 (22–25%).

The high multi-family housing is only located in a few parts of the city. It consists of single groups of apartment blocks located in 3 basic fields—fields Nos. 12, 13, and 26. The area of high multi-family housing is 0.5 to 3% of the area of the basic field.

Larger workplaces in the city are located on the outskirts of residential buildings, mainly in the northern and eastern parts of the city; most often, they are grouped in larger clusters. The economic zone is located in the eastern part of the city. It is located within the area of nine basic fields (fields Nos. 14, 15, 16, 21, 22, 23, 29, 30, and 37). In total, workplaces are located in 22 basic fields. The largest group of workplaces is located in field No. 4 (29% of the field area) and in fields Nos. 23, 29, and 37 (19–24%).

There are more than a dozen educational institutions in the city of Czeladź. Among them, we distinguish 8 kindergartens, 6 elementary schools, the Complex of Special Schools, the Complex of General and Technical Schools, and the College of Social Services Employees. However, the majority of primary school and kindergarten pupils attend facilities located close to their places of residence; therefore, only post-primary and higher schools were included in the analysis. There are two such facilities in the city, both are located in basic field No. 13.

Assessing the potential transport demand, the following assumptions about the density of people using a specific category of facility were made:

- for single-family housing—4 people per building (i.e., $a_{SF} = 4$),
- for multi-family buildings—1 person per 35 m² (i.e., $a_{MF} = 1/35$),
- for workplaces—2 people per 100 m².

Furthermore, it was assumed that the living area of multi-family buildings is 85% of the total building area (i.e., $b_{MF} = 0.85$) and that the coefficients determining the average number of stories of low and high multi-family housing equal, respectively, $K_{LMF} = 4$ and $K_{HMF} = 10$. The number of pupils and students from secondary and higher schools in the i -th basic field has been determined based on data from the Ministry of Education and Science [77]

The potential transport demand was independently assessed for each field based on the aggregated measure $Total_Z_i$, according to the Formula (6). In the further part of the analysis, a nine-point scale of levels was adopted. The ranges corresponding to individual levels are presented in Table 1.

Table 1. Levels of measures of public transport demand.

Number of the Level $ML(Total_Z_i)$	Color On the Map	Range of Numerical Values of a Measure of the Potential Transport Demand for Each Level
		$Total_Z_i [Persons/km^2]$
0		0
1		(0–1000]
2		(1000–2000]
3		(2000–3000]
4		(3000–4000]
5		(4000–5000]
6		(5000–6000]
7		(6000–7000]
8		(7000–8000]

Figure 6 shows the results of the assessment of the potential transport demand on the city map with the area divided into basic fields.

The highest eighth level of potential transport demand was observed in field No. 36. This results mainly from the presence of single-family and low multi-family housing in this field, occupying a total of about 60% of its area. The high level of potential transport demand (i.e., level 7) also occurs in fields Nos. 12, 13, 35, and 44. In fields Nos. 12 and 13 it results mainly from the presence of high multi-family buildings, and in fields Nos. 35 and 44—from the location of workplaces. In all these fields, the share of the built-up area is at the level of 30% of the field area.

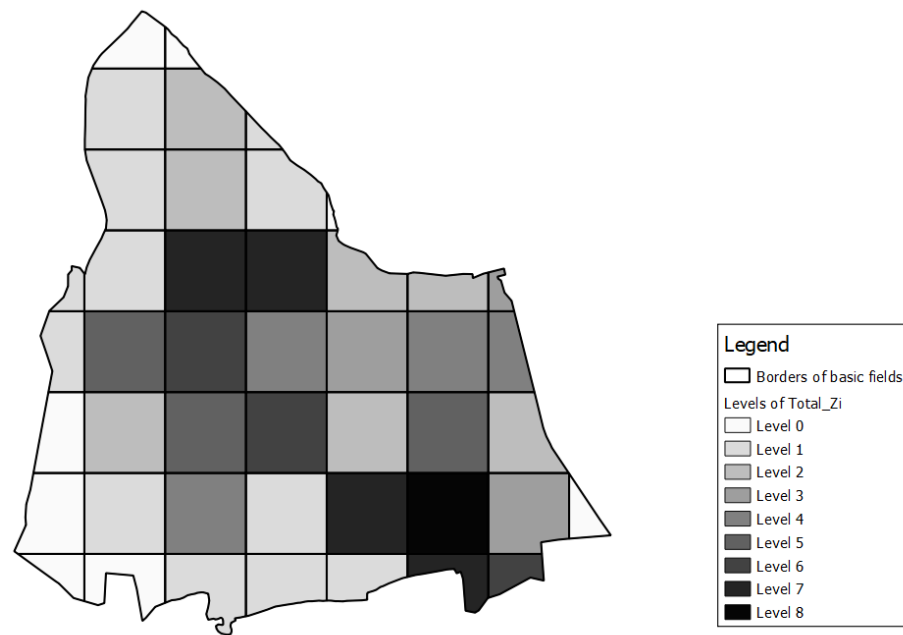


Figure 6. Result of the assessment of the potential transport demand.

4.3. Results of the Assessment of Accessibility of Public Transport

The organizer of public collective transport in Czeladź is the Metropolitan Transport Authority (in Polish: ZTM). It is a budgetary unit established by the Metropolis GZM to organize, plan, and manage public transport in the area of the Metropolis.

There are two tram lines and 18 bus lines in the city of Czeladź—13 regular lines, 2 accelerated lines, and 3 night lines, as presented in Appendix A. The tram and bus routes along with the location of the stop stations in the city of Czeladź are presented in Figure 7.

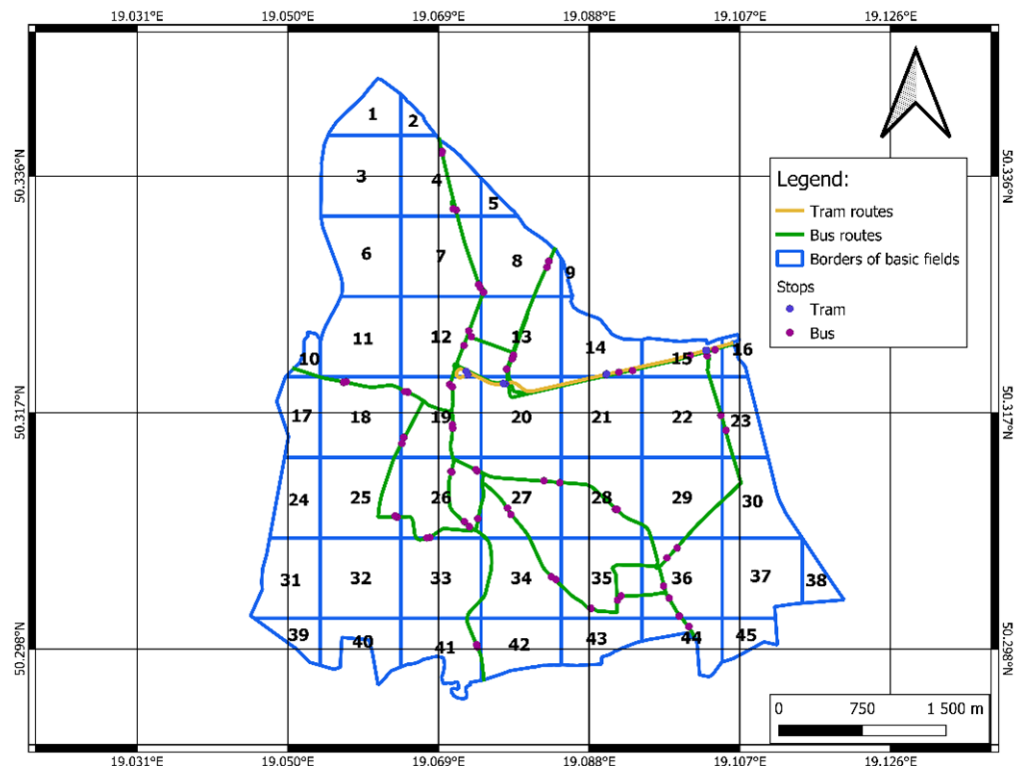


Figure 7. The tram and bus routes along with the location of the stop stations in the area of the city of Czeladź.

Tram lines Nos. 22 and 42 connect the city center and the areas along the national road No. 94 with Będzin and Dąbrowa Górnicza. Line No. 42 runs only on Saturdays; therefore, it was not included in the analysis. Line No. 22 runs most of the day every 20 min in each direction.

Bus lines connect the city center and individual parts of the city with 9 cities (Sosnowiec, Będzin, Katowice, Wojkowice, Siemianowice Śląskie, Piekary Śląskie, Mysłowice, Dąbrowa Górnicza, and Bytom). They run at different frequencies during the day. During the morning and afternoon rush hours, lines Nos. 11, 61, 723, 800, and 814 run approximately every 30 min in each direction, lines Nos. 27, 42, 43, and 88 run every 40–50 min, lines Nos. 35, 100, 133, 911, and 935 run approximately every 60 min in each direction, while line No. 235 runs every 80–90 min. In the peak period, most lines run every 50–60 min in each direction. The exceptions are lines Nos. 11 and 723, which run approximately every 30 min, line No. 61 with the headway of 45 min, and line No. 235, which runs every 80 min. In the periods before the morning rush and after the afternoon rush, most lines run less regularly and less frequently than during the rest of the day. Bus lines Nos. 902N, 904N, and 911N run only during the night hours, therefore, they were not included in the analysis.

There are 31 stops in the city of Czeladź, with a total of 71 stop stations, located in 21 of 45 basic fields. The largest number of stop stations is in field No. 26 (9 stop stations) and in field No. 19 (8 stop stations).

The stops are served by a different number of lines, mostly by three bus lines. There are 18 such stations in the city, 15 stations are used by two bus lines, and 12 stations (8 tram stations and 4 bus stations) are served by one line. The largest number of lines serves stations No. 58 (12 bus lines) and Nos. 54 and 59 (11 bus lines).

When assessing the accessibility of the public transport service for each basic field, the values of the measures were determined according to the Formulas (7)–(10), and then each of them was assigned to an appropriate level. The higher the level of the measure, the better the accessibility of public transport.

To conduct a comparative analysis and assess the degree of compliance of each measure of accessibility of public transport (i.e., D_i , L_i , $TI_i(t)$, and BF_i) with the aggregated measure of potential transport demand $Total_Z_i$, a nine-point scale of levels was adopted for all measures. The ranges corresponding to the individual levels for each measure are presented in Table 2.

Table 2. Levels of accessibility measures of public transport services.

Number of the Level $ML(D_i)$ $ML(L_i)$ $ML(TI_i(t))$ $ML(BF_i)$	Color on the Map	Range of Numerical Values of a Measure of Public Transport Supply for Each Level			
		D_i [Stop Stations/km ²]	L_i [Lines/Stop Station]	$TI_i(t)$ [Minutes]	BF_i [Basic Fields]
0		0	0	0	0
1		(0–3]	(0–1]	(35–40]	(0.0–2.5]
2		(3–6]	(1–2]	(30–35]	(2.5–5.0]
3		(6–9]	(2–3]	(25–30]	(5.0–7.5]
4		(9–12]	(3–4]	(20–25]	(7.5–10.0]
5		(12–15]	(4–5]	(15–20]	(10.0–12.5]
6		(15–18]	(5–6]	(10–15]	(12.5–15.0]
7		(18–21]	(6–7]	(5–10]	(15.0–17.5]
8		(21–24]	(7–8]	(0–5]	(17.5–20.0]

The results of the assignment of levels to basic fields for each measure of the assessment of accessibility of public transport are presented in Figure 8. The assessment of the accessibility of the public transport applies only to fields with at least one stop station. There are 21 such fields in the city of Czeladź, which is about 47% of all basic fields in this city.

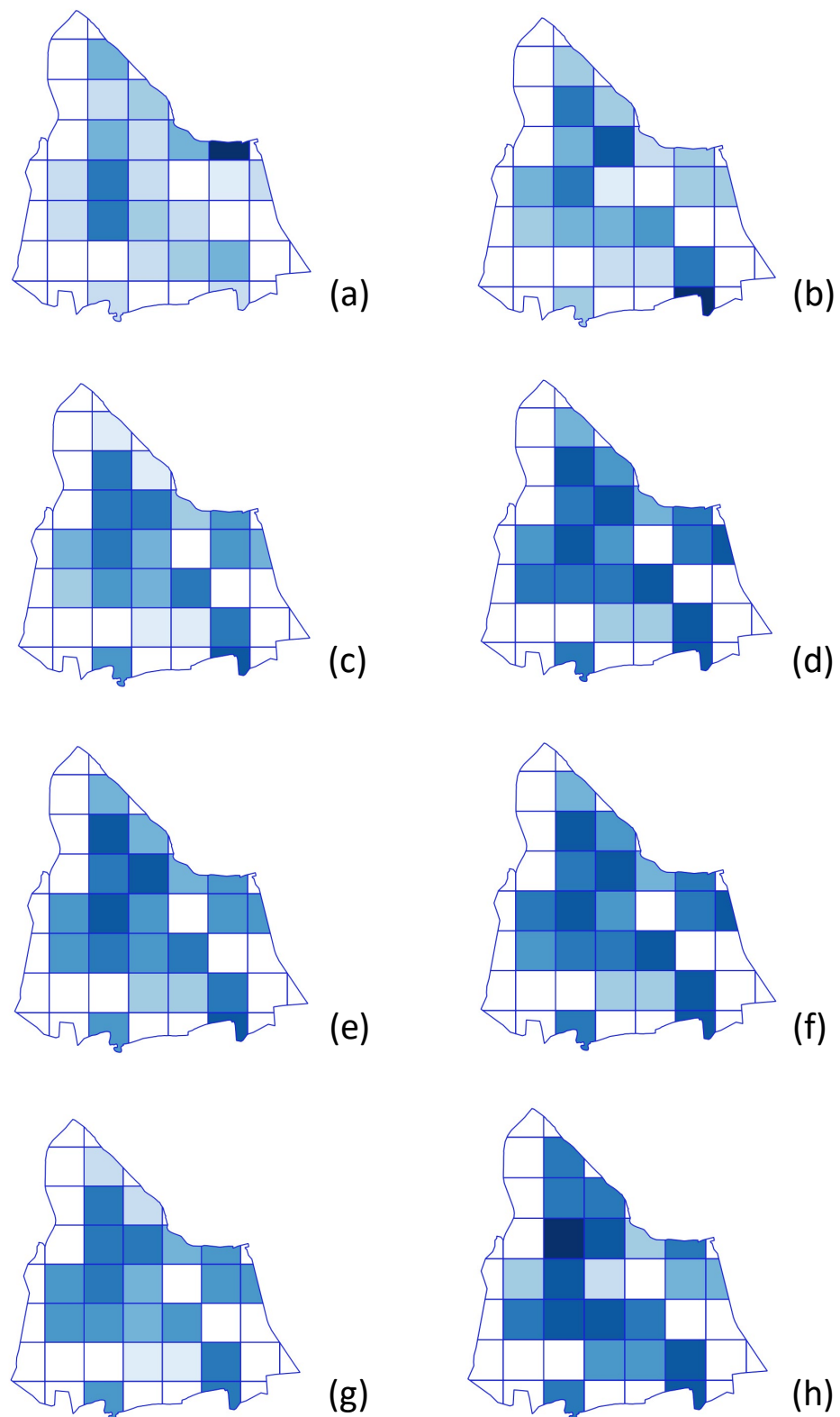


Figure 8. Results of the assessment of accessibility of public transport in the city of Czeladź; (a) density of stop stations D_i , (b) average number of lines serving the single stop station L_i , (c–g) average time interval between successive departures of public transport vehicles from the stop station for each of the five time periods $TI_i(t)$, (h) number of basic fields associated by public transport with the field BF_i .

The highest density of stop stations is in field No. 15 (over 21 stop stations per km², level 8) and in fields Nos. 19 and 26 (15 to 17 stop stations per km², level 6), as well as in fields Nos. 4, 12, 14, and 36 (9 to 11 stop stations per km², level 4). The lowest value of the measure is for fields Nos. 7, 18, 20, 22, 25, 28, and 34 (2 to 5 stop stations per km², level 1 or 2).

The largest number of lines serves the stop stations in basic field No. 44 (8 lines, level 8) and in fields Nos. 7, 13, 19, 28, and 36 (5 to 7 lines, level 5 to 7). The smallest value of the measure is for fields Nos. 14, 20, 34, and 35 (1 to 2 lines, level 1 to 2).

The measure of the frequency of running in particular periods is the average time interval between successive departures from each station in the basic field. The measure is estimated for five periods defined in Section 3 and presented in Figure 8c–g.

In the period before the morning peak (i.e., from 4 a.m. to 6 a.m.—Figure 8c), the highest frequency occurs in field No. 44 (departures every 8 min on average, level 7) and in fields Nos. 7, 12, 13, 19, 28, and 36 (departures every 8 min, 12 to 15 min, level 6). The least frequent stop stations are located in fields Nos. 4, 8, 34, and 35 (departures every 36 to 40 min, level 1).

During the morning rush hour (i.e., from 6 a.m. to 9 a.m.—Figure 8d), the most frequently operated stop stations are located in fields Nos. 7, 13, 19, 28, 36, and 44 (departures on average every 5 to 9 min, level 7) and in fields Nos. 12, 15, 22, 23, 26, 27, and 41 (departures every 10 to 13 min, level 6). The lowest frequency of runs is in fields Nos. 4, 14, 34, and 35 (departures every 22 to 26 min, level 3 or 4).

In the peak period (i.e., from 9 a.m. to 2 p.m.—Figure 8e), the highest frequency of runs occurs in fields Nos. 7, 13, 19, 36, and 44 (departures on average every 6 to 10 min, level 7) and in fields Nos. 12, 26, and 28 (departures every 11 to 12 min, level 6). The least frequent are service of the stations in fields Nos. 4, 8, 14, 34, and 35 (departures every 23 to 27 min, level 3 or 4).

During the afternoon rush hour (i.e., from 2 p.m. to 5 p.m.—Figure 8f), the most common lines serve the stop stations in fields Nos. 7, 12, 13, 19, 23, 28, 36, and 44 (departures every 6 to 10 min on average, level 7) and in fields Nos. 15, 18, 22, 26, 27, and 41 (departures every 11 to 15 min, level 6). The lowest frequency of runs is in fields Nos. 4, 14, 34, and 35 (departures every 21 to 28 min, level 3 or 4).

In the period after the afternoon rush (i.e., from 5 pm to 11 pm—Figure 8g), the highest frequency of runs occurs in fields Nos. 7, 12, 13, 19, 36, and 44 (departures on average every 10 to 15 min, level 6) and in fields Nos. 15, 18, 22, 23, 25, 26, 28, and 41 (departures every 16 to 20 min, level 5). The least frequently serviced stations are located in fields Nos. 4 and 8 (departures every 30 min, level 2) and in fields Nos. 34 and 35 (departures every 40 min, level 1).

The number of basic fields associated with the field under study with the use of public transport is the number of fields with stop stations, directly served by the lines that serve the stations in the field under study. Most basic fields are related to field No. 12 (18 basic fields, level 8) and fields Nos. 13, 19, 26, 27, 36, and 44 (16 to 17 basic fields, level 7), as well as to fields Nos. 4, 7, 8, 15, 25, 28, and 41 (13 to 15 basic fields, level 6). This means that these fields are characterized by the highest level of impact. The smallest value of the measure is for fields Nos. 14, 18, and 20 (3 to 7 basic fields, level 2 or 3).

For each basic field, an aggregate measure $AML(i, t)$, i.e., weighted average of levels of individual measures to assess the accessibility of public transport. It was determined according to Formula (16), assuming the same weight (equal to 0.25) for each of the four measures. Figure 9 shows the results for five periods.

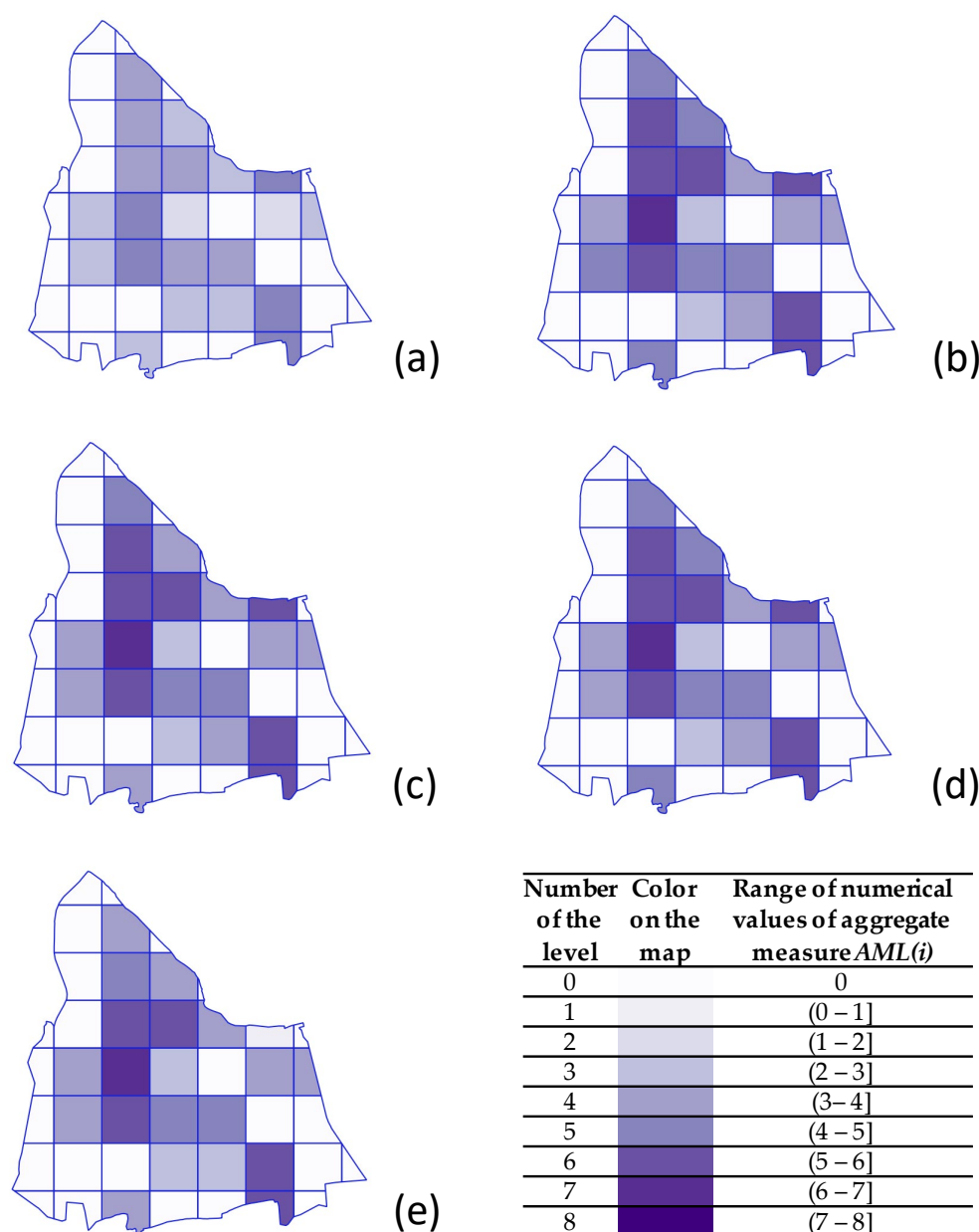


Figure 9. Results of the aggregated assessment of accessibility of the public transport- values of the measure $AML(i, t)$ for periods, (a) from 4 a.m. to 6 a.m., (b) from 6 a.m. to 9 a.m., (c) from 9 a.m. to 2 p.m., (d) from 2 p.m. to 5 p.m., and (e) from 5 p.m. to 11 p.m.

When analyzing the results presented in Figure 9, very similar levels of aggregated assessment of the accessibility of public transport were observed during the morning and afternoon rush hours (Figure 9b, d). The only difference concerns field No. 25, which is characterized by one level higher in the value of $AML(i, t)$ in the morning peak. The lowest values of the levels of the aggregated measure $AML(i, t)$ were observed from 4 a.m. to 6 a.m., i.e., in the period before the morning peak.

4.4. Comparative Analysis

According to the method presented in Figure 1, the comparative analysis consists in determining the degree of compliance of the assessment of potential transport demand with the assessment of accessibility of public transport. The results for individual measures, i.e., $ADL(D_i)$, $ADL(L_i)$, $ADL(TI_i(t))$, and $ADL(BF_i)$, estimated according to the Formulas (11)–(14), for five periods are shown in Figure 10.

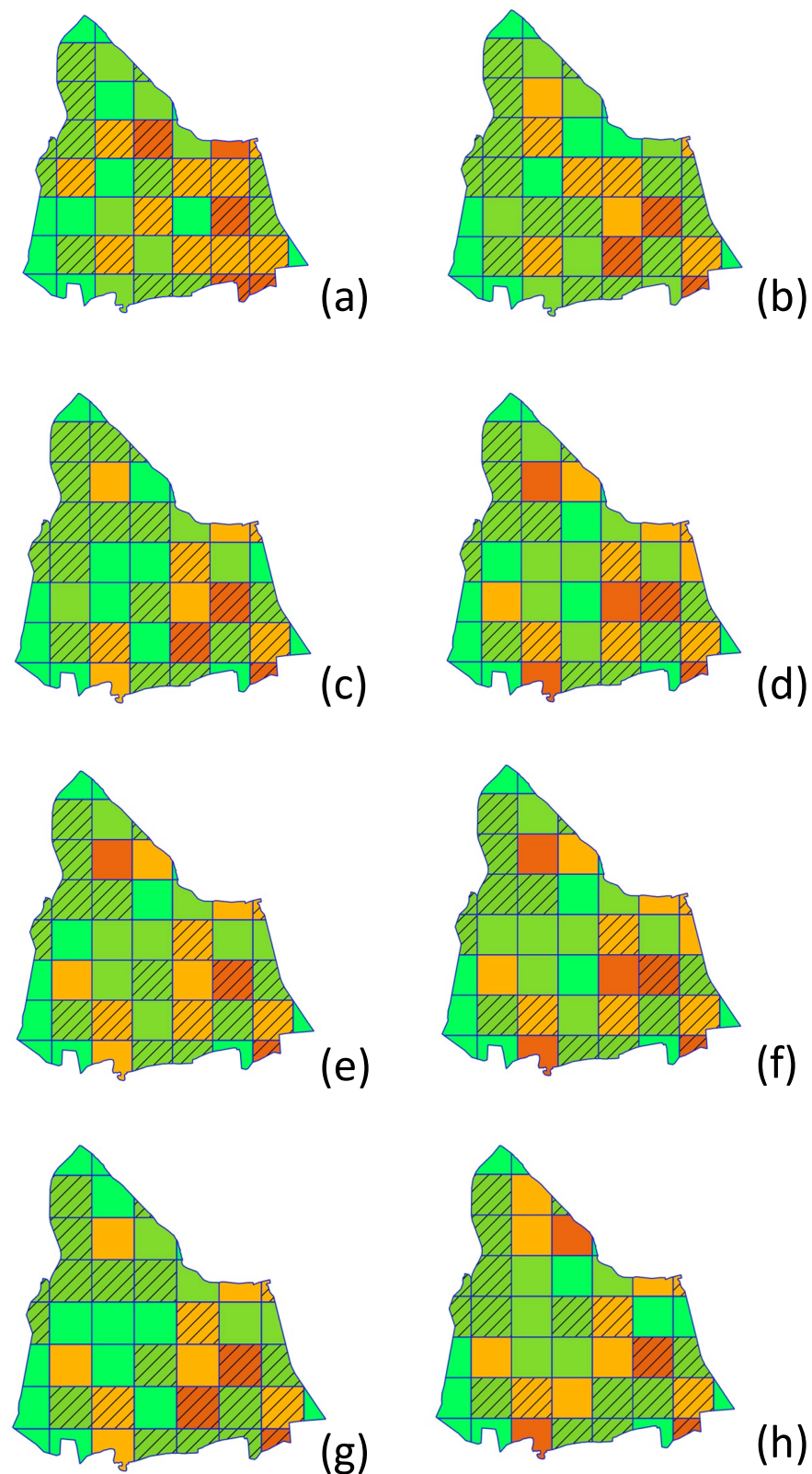


Figure 10. Results of the absolute difference between the levels of individual measures to assess the accessibility of public transport and the level of potential transport demand; (a) $ADL(D_i)$ —for density of stop stations, (b) $ADL(L_i)$ —for average number of lines serving the single stop station, (c–g) $ADL(TI_i(t))$ —for average time interval between successive departures of public transport vehicles from the stop station for each of the five periods, (h) $ADL(BF_i)$ —for number of basic fields associated by public transport with the analyzed field.

In Figure 10, the values marked in red mean the greatest inconsistencies in the assessment of the potential transport demand and the accessibility of public transport. Plain fields indicate the excess of the offer in relation to the demand, while patterned fields indicate the disproportions resulting from the low level of accessibility of public transport services in the presence of potential transport demand. These fields may indicate places where it is worth expanding the offer to meet the demand. The green fields show a similar level in terms of assessing potential transport demand and the accessibility to public transport.

In the area of eight basic fields (that is, fields Nos. 1, 2, 9, 24, 31, 38, 39, and 40), there are no traffic generators and no stop stations. In most of the remaining fields, where there are no stop stations, there is a very low demand for public transport services (level 1). The exceptions are fields Nos. 21, 29, 33, 37, and 45. The greatest demand among the above fields is in field No. 29 (level 5) and in fields Nos. 21, 33, and 37 (levels 3 to 4), and the lowest in field No. 45 (level 2).

The number of basic fields with a higher level of the stop density measure in relation to the demand is 7. The greatest difference in levels occurs in field No. 15 (7 levels) and in fields Nos. 4, 8, and 14 (2 to 3 levels). The lower level of the measure in relation to the demand occurs in nine fields. The greatest difference in levels occurs in fields Nos. 13, 35, and 36 (4 to 6 levels) and in fields Nos. 12, 18, 20, 22, and 27 (2 to 3 levels). For the remaining basic fields with stops, the level of the measure is equal to the level of transport demand.

A higher value of the measure of the average number of lines that serve stopping stations in relation to demand occurs in 11 basic fields. The greatest difference in levels occurs in fields Nos. 7 and 44 (4 to 5 levels) and in fields Nos. 8, 15, 28, and 41 (2 to 3 levels). The lower value of the measure in relation to the demand occurs in nine fields. The biggest difference is in field No. 35 (5 levels) and in fields Nos. 12, 20, 27, and 36 (2 to 3 levels). In field No. 19, the level of the measure corresponds to the level of the demand.

For the frequency measure, the highest levels are reached during peak hours, and the lowest levels are reached in the hours before the morning rush and after the afternoon peak. The greatest difference in levels, where the measure is above demand, occurs at peak and peak-to-peak times in fields Nos. 7, 8, 14, 15, 23, 25, 28, 41, and 44 (3 to 5 levels). In the remaining time intervals, the maximum difference is 3 to 4 levels. On the other hand, for the fields where the measure reaches lower levels than the demand, the greatest differences are found in field No. 35 (4 levels in the peak hours and in the inter-peak period, and 6 levels in the remaining periods).

A higher value for the measure of the number of basic fields associated with the field under study in relation to the demand occurs in 15 fields. The greatest difference in levels occurs in fields Nos. 4, 7, 8, 15, 23, 28, 34, 41, and 44 (4 to 5 levels) and in fields Nos. 14, 23, and 26 (2 levels). The lower value of the measure in relation to the demand appears in 5 fields. The biggest difference is in fields Nos. 18, 20 and 35 (2 levels). In field No. 22, the level of the measure corresponds to the level of demand for public transport services.

When analyzing the maps presented in Figure 10 for individual measures, it can be noted that the best accessibility of public transport in relation to the demand occurs in fields Nos. 4, 7, 8, 14, 15, 23, 25, 28, 34, 41, and 44. All the above-mentioned fields are characterized by a low demand for public transport services (levels 1 to 2). Good accessibility also occurs in fields located along the main routes in the north-south axis (fields Nos. 19, 22, and 26).

The worst accessibility of public transport in relation to the demand occurs in fields Nos. 21, 29, 33, 35, and 37. In field No. 35, there is an insufficient accessibility of public transport, whereas in the remaining fields there are no stop stations. The lower availability also occurs in fields Nos. 13, 36, and 45. There are no stops in field No. 45, and in fields Nos. 13 and 36, there is the highest demand and a relatively low density of stop stations, while for the remaining measures the difference is a maximum of 2 levels.

The results for the aggregated measures $AADL(i, t)$ estimated according to the Formula (15) for five periods are presented in Figure 11.

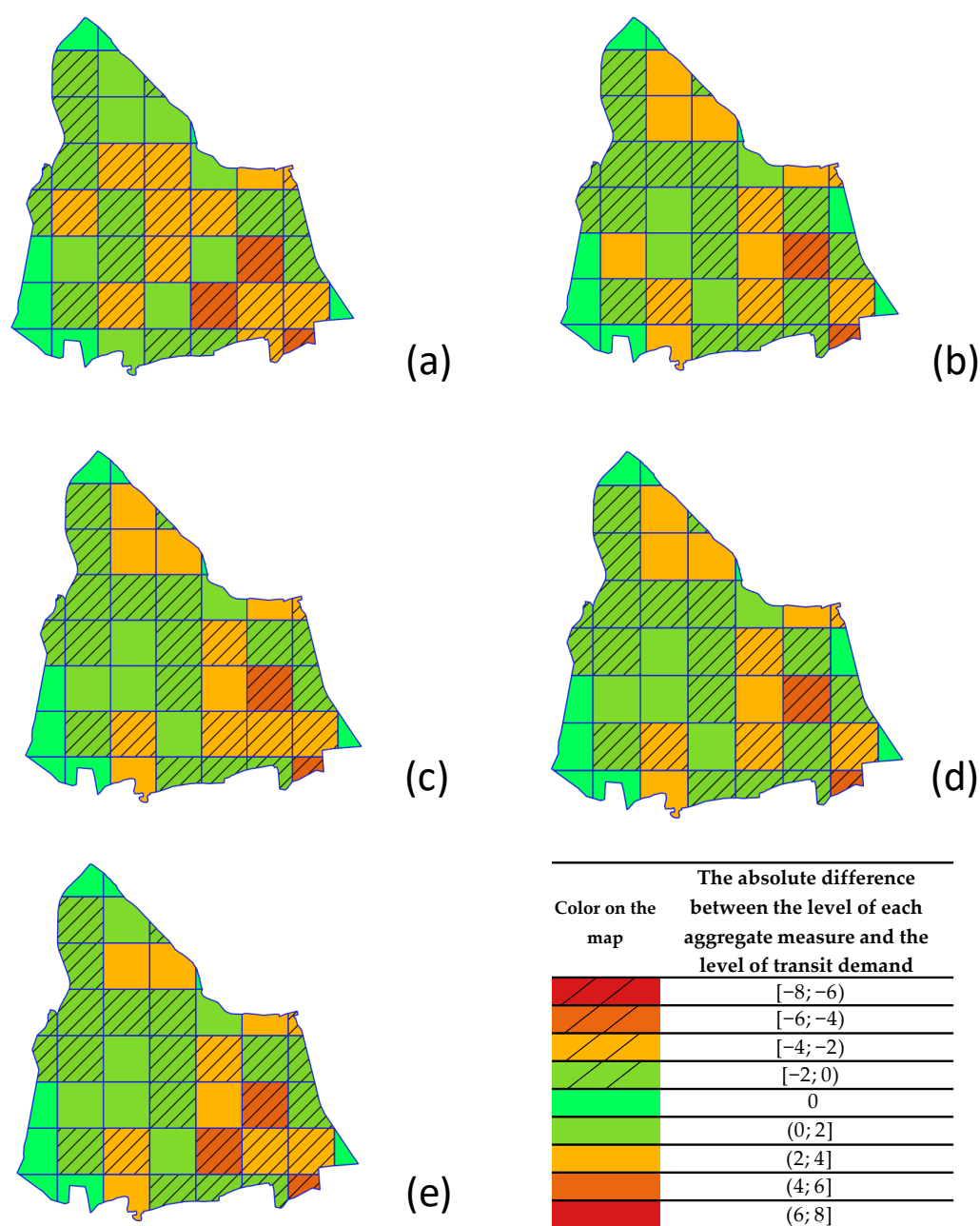


Figure 11. Results of the absolute difference between the level of aggregate measure for assessing the accessibility of public transport and the level of potential transport demand—values of the measure $AADL(i, t)$ for periods, (a) from 4 a.m. to 6 a.m., (b) from 6 a.m.–9 a.m., (c) from 9 a.m. to 2 p.m., (d) from 2 p.m. to 5 p.m., and (e) from 5 p.m. to 11 p.m.

When analyzing the values of the aggregate measure in individual periods presented in Figure 11, a relatively small difference between the level of potential transport demand and the level of accessibility of public transport can be noticed. The largest disproportions in terms of the compatibility of the public transport offer and the demand are found in fields Nos. 29 and 45, while field No. 45 is not entirely within the city area. This situation occurs throughout the day. Additionally, in the early morning periods (i.e., period 1—from 4 a.m. to 6 a.m.—presented in Figure 11a) and in the evening (i.e., period 5—from 5 p.m. to 11 p.m.—presented in Figure 11e) there is a significant mismatch in this respect—they are also in field No. 35, which is an area where low multi-family housing predominates.

The maps presented in Figures 10 and 11 show specific locations (areas) where there are disproportions between the potential demand for transport and the accessibility of

public transport. By analyzing spatial development, the reasons for this situation can be determined and the places where improving accessibility to public transport is needed, can be indicated.

5. Discussion

In addition to the spatial analyses shown in Figures 10 and 11, it is also worth assessing the scale of the mismatch between public transport accessibility and potential transport demand. For this purpose, Tables 3 and 4 were prepared showing the percentages of fields with the values of individual and aggregated measures falling within the respective ranges.

Table 3. Percentages of basic fields with the values of individual measures that fall within the respective ranges.

Range of Value of the Measure	Percentage Share of Basic Fields						
	$ADL(D_i)$	$ADL(L_i)$	$ADL(TI_i(1))$	Individual Measures		$ADL(TI_i(4))$	$ADL(BF_i)$
				$ADL(TI_i(2))$	$ADL(TI_i(3))$		
{−8; −7}	0%	0%	0%	0%	0%	0%	0%
{−6; −5}	9%	7%	7%	4%	4%	4%	4%
{−4; −3}	22%	13%	9%	11%	11%	11%	9%
{−2; −1}	27%	36%	36%	27%	29%	27%	33%
0	27%	24%	33%	27%	24%	24%	31%
{1; 2}	13%	16%	7%	16%	18%	18%	9%
{3; 4}	0%	4%	9%	9%	11%	9%	11%
{5; 6}	2%	0%	0%	7%	2%	7%	0%
{7; 8}	0%	0%	0%	0%	0%	0%	0%

Table 4. Percentages of basic fields with the values of aggregated measures that fall within the respective ranges.

Range of Value of the Measure	Percentage Share of Basic Fields				
	Aggregated Measures				
	$AADL(TI_i(1))$	$AADL(TI_i(2))$	$AADL(TI_i(3))$	$AADL(TI_i(4))$	$AADL(TI_i(5))$
[−8; −6)	0%	0%	0%	0%	0%
[−6; −4)	7%	4%	4%	4%	7%
[−4; −2)	24%	11%	13%	11%	11%
[−2; 0)	31%	40%	40%	40%	40%
0	18%	20%	18%	20%	18%
(0; 2]	18%	9%	11%	11%	13%
(2; 4]	2%	16%	13%	13%	11%
(4; 6]	0%	0%	0%	0%	0%
(6; 8]	0%	0%	0%	0%	0%

For all measures presented in Table 3, the highest levels of non-compliance in the assessment of potential transport demand and accessibility of public transport (that is, levels 7 and 8) were not observed. The largest share of basic fields (more than 67%) shows a high level of compliance (the level is in the range of −2 to 2), but it is worth emphasizing that there are more negative inconsistencies than positive ones. This means that the public transport offer is underestimated more than overestimated.

In the case of aggregate measures presented in Table 4, similar trends were observed to those for individual measures. Furthermore, there were no highest levels of non-compliance (above level 6), and the largest share of fields (above 67%) shows a high level of compliance (the compliance of levels ranges from −2 to 2). The greatest discrepancies were observed in

the period before the morning peak. For 24% of the basic fields, the levels of discrepancy ranged from -2 to -4 during this period.

To improve accessibility to public transport, it is recommended to construct bus stops in field No. 29 in the vicinity of existing workplaces and to create new or increase the frequency of servicing existing bus stops in field No. 35. In the case of field No. 33, most of the buildings are located in the northern part of the field and are located close to the stop stations in field No. 26, therefore it is not recommended to locate additional stations in the field. A similar situation occurs in field No. 21, where the stations are located in the southern part of field No. 14; however, in the case of further expansion of the economic zone, it is recommended to create additional stops and increase the accessibility of public transport. For fields Nos. 13, 36, 37, and 45, if possible, in the existing road system, the location of additional stops may be considered.

The approach presented in the article is the first stage of the assessment of accessibility of public transport by using temporal and spatial analysis. Figure 12 shows the concept of extending the method by the next stage of in-depth analyses.

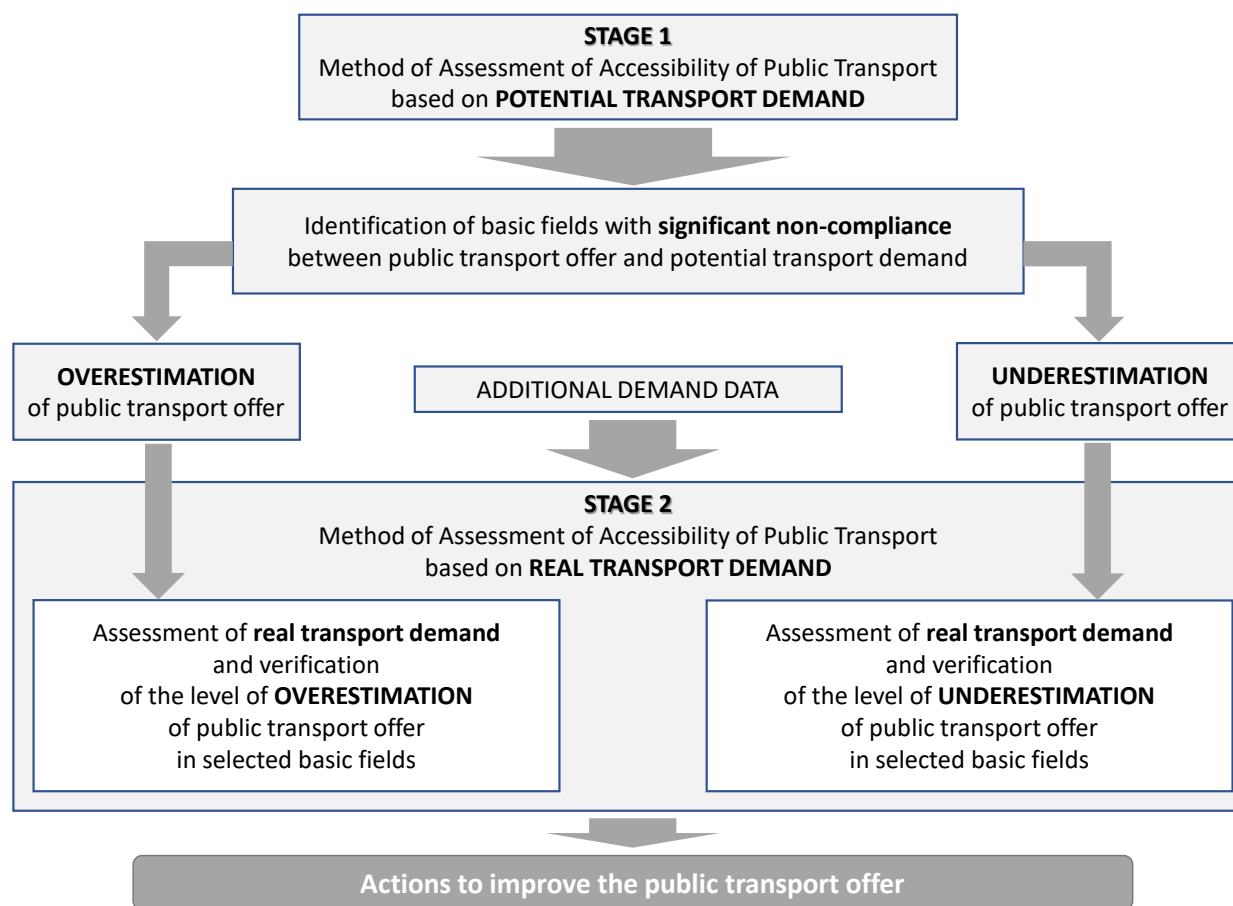


Figure 12. The concept of extending the method of assessment of accessibility of public transport by using temporal and spatial analysis.

The result of the comparative analysis, which is the last stage of the adopted method of the assessment of accessibility of public transport presented in Figure 1, is the identification of basic fields in which there are significant discrepancies between the public transport offer and the potential transport demand defined in a simplified way. According to the proposed approach, this identification is carried out both on the basis of the values of the individual measures $ADL(D_i)$, $ADL(L_i)$, $ADL(TI_i(t))$, $ADL(BF_i)$ and the aggregated measures $AADL(i, t)$. The found non-compliance may consist in underestimation or overestimation of the public transport offer.

The main goal of our approach is to match the offer to transport needs. Therefore, in the second stage, the scope of analyses is extended and deepened, considering more accurate measures related to the real demand for transport. However, this process requires the acquisition of additional data.

After the assessment of the actual transport demand in the basic fields with the greatest discrepancies, the level of overestimation or underestimation of the public transport offer is verified, respectively. The results obtained may provide valuable information for decision-makers in terms of activities that improve the level of matching the public transport offer to the identified transport needs.

6. Conclusions

The article presents a method to assess the accessibility to public transport, that considers spatial and temporal aspects. An important element of the method is the comparison of the assessment of the accessibility of public transport with the assessment of potential transport demand. Both values were determined on a nine-point scale. During the analysis, spatial and temporal differences in accessibility of public transport were considered, which was reflected in the research results.

The areas with low potential transport demand, located on the outskirts of the city's buildings, and along the main routes, are characterized by the greatest compliance in terms of the accessibility of public transport in relation to the demand. In turn, the greatest disproportions in this regard were observed in areas characterized by a lack of access to public transport infrastructure, as well as in areas of the city with the highest demand for public transport, which do not have sufficient transport infrastructure.

The highest accessibility in terms of time occurs during the morning and afternoon rush hours, and the lowest in the early morning and evening hours.

The developed research methodology allows for a simplified assessment of the degree to which transport needs are met in individual parts of the city. However, it does not take into account the exact location of the stop stations within the basic field. In the case of further development of the method, it is recommended to consider the location of transport infrastructure and traffic generators in the area of separated parts of the city. Furthermore, the size of the areas into which the city is divided, when choosing too large or too small, can affect the values of some measures [75]. The proposed approach can be treated as the first preliminary stage of research. In further in-depth analyses focused on the basic fields, where significant discrepancies between the public transport offer and the potential transport demand were found, the following should be considered:

- use of transport models built for a given area,
- using other factors to estimate accessibility by public transport,
- conducting questionnaire surveys to identify travel demand flows (OD matrix),
- carrying out careful analyses concerning the supply between individual traffic zones.

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Appendix A Appendix A

Table A1. Tram and bus lines.

Number of Line	Direction	Municipalities Served	Average Time Interval between Successive Departures (Minutes)				
			4 a.m. –6 a.m.	6 a.m. –9 a.m.	9 a.m. –2 p.m.	2 p.m. –5 p.m.	5 p.m. –11 p.m.
Tram lines							
22	Tworzeń Huta Katowice— Czeladź Kombatantów	Będzin, Dąbrowa Górnicza	16	20	20	20	23
	Czeladź Kombatantów— Tworzeń Huta Katowice		25	20	20	20	22
42	Czeladź Kombatantów Dąbrowa Górnicza Urząd Pracy Pętla	Będzin, Dąbrowa Górnicza	The line runs only on Saturdays				
Regular bus lines							
11	Piotrowice Pętla—Czeladź Wojkowska Pętla	Sosnowiec, Katowice	23	30	30	30	50
	Czeladź Wojkowska Pętla—Piotrowice Pętla		26	30	30	30	48
27	Katowice Plac Wolności—Tworzeń Huta Katowice	Katowice, Siemianowice Śląskie, Będzin, Dąbrowa Górnicza	57	35	60	40	66
	Tworzeń Huta Katowice—Katowice Plac Wolności		53	50	56	40	80
35	Kosztowy Pętla—Czeladź Wojkowska Pętla	Sosnowiec, Mysłowice	61	60	60	60	63
	Czeladź Wojkowska Pętla—Kosztowy Pętla		60	60	60	61	60
42	Będzin Kościuszki— Bytom Dworzec	Bytom, Piekary Śląskie, Siemianowice Śląskie, Będzin	46	46	60	45	46
	Bytom Dworzec— Będzin Kościuszki		50	46	60	50	43
43	Katowice Plac Wolności—Wojkowice Fabryczna—Katowice Plac Wolności (circular line)	Katowice, Siemianowice Śląskie, Piekary Śląskie, Wojkowice, Będzin	74	39	49	32	50
61	Będzin Kościuszki— Katowice Dworzec	Katowice, Sosnowiec, Będzin	36	30	45	43	59
	Katowice Dworzec— Będzin Kościuszki		59	30	47	30	55
88	Sosnowiec Urząd Miasta—Wojkowice Fabryczna	Sosnowiec, Będzin, Wojkowice	36	47	50	45	95
	Wojkowice Fabryczna—Sosnowiec Urząd Miasta		55	49	50	43	68
100	Sosnowiec Urząd Miasta—Wojkowice Fabryczna	Sosnowiec, Będzin, Wojkowice	63	60	60	67	76
	Wojkowice Fabryczna—Sosnowiec Urząd Miasta		60	61	60	65	76
133	Katowice Plac Wolności—Wojkowice Park—Katowice Plac Wolności (circular line)	Katowice, Siemianowice Śląskie, Piekary Śląskie, Wojkowice, Będzin	64	61	50	49	109
235	Sosnowiec Szpital Wojewódzki— Czeladź Szpital	Sosnowiec, Będzin	70	90	80	80	-
	Czeladź Szpital—Sosnowiec Szpital Wojewódzki	Sosnowiec	70	84	80	80	-

Table A1. Cont.

Number of Line	Direction	Municipalities Served	Average Time Interval between Successive Departures (Minutes)				
			4 a.m. –6 a.m.	6 a.m. –9 a.m.	9 a.m. –2 p.m.	2 p.m. –5 p.m.	5 p.m. –11 p.m.
723	Zagórze Zajezdnia—Czeladź Wojkowicka Pętla	Sosnowiec	33	31	33	33	54
	Czeladź Wojkowicka Pętla—Zagórze Zajezdnia		50	30	33	36	47
911	Katowice Dworzec—Czeladź Wojkowicka Pętla	Sosnowiec, Katowice	60	125	60	82	53
	Czeladź Wojkowicka Pętla—Katowice Dworzec			60	164	63	47
935	Ćmok Pętla—Czeladź Wojkowicka Pętla	Sosnowiec, Mysłowice	66	60	60	60	60
	Czeladź Wojkowicka Pętla—Ćmok Pętla		55	60	60	63	60
Frequent service bus lines							
800	Będzin Kościuszki—Katowice Piotra Skargi	Katowice, Sosnowiec, Będzin	33	33	52	33	98
	Katowice Piotra Skargi—Będzin Kościuszki		45	30	57	32	85
814	Tworzeń Huta Katowice—Katowice Piotra Skargi	Katowice, Sosnowiec, Będzin, Dąbrowa Górnicza	30	35	54	30	47
	Katowice Piotra Skargi—Tworzeń Huta Katowice		26	28	42	30	53
Night bus lines							
902N	Zagórze Zajezdnia— Czeladź—Będzin—Dąbrowa Górnicza—Zagórze Zajezdnia	Sosnowiec, Będzin, Dąbrowa Górnicza	The lines run only during the night hours				
904N	Zagórze Zajezdnia— Będzin Kościuszki	Sosnowiec, Będzin					
911N	Katowice Dworzec—Czeladź Wojkowicka Pętla (-Wojkowice Fabryczna)	Katowice, Sosnowiec (Wojkowice)					

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