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Piotr SOCZÓWKA

Silesian University of Technology
Kraśnińskiego 8, 40-019 Katowice, Poland
Corresponding author. E-mail: piotr.soczowka@polsl.pl

METHOD OF CLASSIFICATION OF SPATIAL UNITS FOR TRANSIT-RELATED ANALYSES

Summary. Transport activity may lead to multiple problems that decrease the quality of life of commuters. Among the many methods used to cope with these problems, considerable attention has been paid to the development of transit. Effective transit systems may encourage inhabitants to move away from the use of private cars to mass transport. It is therefore essential to identify the factors that contribute to high levels of ridership. Among such factors, land use mixture is often mentioned. However, it is unclear how it affects ridership. Therefore, to encourage further studies, it is important to develop methods of classification of spatial units in terms of land use mixture. Such analyses should be conducted for similar levels of transit supply. Hence, the aim of this paper was to develop a method of classification of spatial units in terms of land use mixture and transit supply. The method uses different characteristics of land use and transit supply as factors in the process of classification. The proposed method was used for an area in the city of Katowice to demonstrate its application.

1. INTRODUCTION

The development of modern urban and metropolitan areas is associated with multiple problems that negatively affect the quality of life of people [1]. The expansion of cities as well as the development of new activities, which are often spatially separate, create a demand for traveling. In addition, a great number of trips are also associated with regular activities such as commuting to and from the workplace or school [2]. Transport, being an inevitable part of human existence, also leads to several unfavorable phenomena. These include congestion, pollution, noise, and traffic incidents [3]. Hence, in metropolitan areas, the mobility of commuters should be managed in a way that is in accordance with the idea of sustainable development [4, 5]. As the report of Brundtland Commission states, sustainable development is “such that meets the needs of the present without compromising the ability of the future generations to meet their own needs” [6]. On this basis, the concept of sustainable mobility in urban areas has been created. Among the goals of sustainable mobility are improvement of quality of life and reduction of the negative influence of transport [7].

There are different tools of sustainable mobility. However, as most problems associated with transport activity are related to the dominant role of individual transport, many of them pertain to the increase of the significance of transit [8]. Moreover, multiple legal acts and strategic documents also highlight the role of transit in shaping the sustainable system of transport in urban areas [9]. To enhance the significance of transit, it is indispensable to provide a level of service that is desirable from the passengers’ point of view [10]. Different aspects of service influence the way passengers perceive transit, i.e. quality of vehicles, accessibility, the timetable (frequency, number of courses, span, punctuality), fares, safety, and location of stops [11-13]. Each aspect is associated with different

demands of passengers. Therefore, many studies have been conducted to analyze the factors that influence the decision of potential passengers in choosing transit.

Most studies have been focused on the identification of variables that influence the ridership at a given stop, expressed as the number of passengers who board or alight from transit vehicles at that stop. Transit stops should be located in places that provide the highest ridership, while ensuring proper safety conditions. Among the factors that influence ridership are socio-economic factors, factors associated with land use, characteristics of the station, and characteristics of the service [14].

Factors associated with land use represent built-environment characteristics that have an impact on ridership. In the literature, often, a three-dimensional approach to the role of land use is adopted, based on three factors: density, diversity, and design [15]. Although usually measures pertaining to density are the most important variables in direct ridership models (density in this context is associated both with population density and with employment density), two other factors also contribute to the level of ridership at a stop. Design pertains to proper connectivity of the network available for pedestrians who walk to the transit stops and with provision of sidewalks and other facilities for walking. Studies have shown that a design that is suitable for pedestrians and encourages walking may have a positive influence on ridership [16]. Diversity, on the other hand, should be understood as land use mixture. However, studies suggest that the influence of land use mixture may be more complex; thus, this factor should be studied in depth to determine its impact on ridership [15].

Research on the influence of land use mixture on ridership requires a universal method of determination of such diversity expressed in numerical values for different spatial units. The ridership is usually calculated at a stop level and hence the built-environment characteristics of the stop should be taken into account. This requires a proper division of the area into smaller spatial units.

In general, there are two approaches to the division of the area: division into regularly shaped spatial units and division into irregularly shaped spatial units [17]. In the case of the first approach, the area is divided into basic fields. Such a division requires the imposition of a regular grid on the area. The literature suggests using three plane figures to create such a grid: squares, hexagons, or triangles [18]. This type of division is called regular tessellation of the area [19]. Division into irregularly shaped spatial units is more complex as the method of division and scope depend on the type and purpose of research. In the case of transport studies (i.e. for the purposes of building of a transport model), the area is divided into traffic analysis zones (TAZs) based on the homogeneity of the spatial unit in terms of travel behavior and physical borders of the unit [20].

Land use mixture requires the identification of possible types of land use. The general method of classification of land use involves the following types: urban or built-up, agriculture, rangeland, forest land, water, wetlands, and barren [21]. Sometimes, other types are also identified such as rock and coastal land, minerals and landfill, or unimproved grassland and heathland [22].

Because most of the transit activity takes place in urban areas, where the built environment is dominant, the subdivision of “urban or built-up” type is of particular significance in terms of land use diversity for the purposes of modeling ridership. Many methods of classification of urban or built-up land use are not precise enough for transport purposes when it comes to built environment. Some common classifications of built-up areas are residential, commercial and services, transport, industrial and commercial, mixed urban, or built-up land [21]. All these classes may also be subdivided, but the division is usually too general. To model ridership in the most precise way, it is necessary to identify the influence of each individual type of object. Therefore, each method of calculating measures of land use mixture should be adjusted to transit purposes. Existing measures of land use mix usually have the same issue of generality as the classification of land use types. The commonly used land use mix measure, calculated using the entropy formula, assumes five types of land use: residential, commercial, retail, recreation, and civic. Other measures include the dissimilarity index [23].

While this approach may be suitable for many transport studies, in the case of transit and modeling of ridership, more detailed division may be required. Each type of land use encompasses several types of objects, and each object has a unique influence on ridership.

Taking into account existing approaches for the determination of land use mix and purposes of modeling in transit, the main aim of this paper is to develop a general method of classification of spatial units in terms of land use mixture and transit supply for the purposes of transit-related analyses.

The proposed method allows assigning spatial units in urban areas to classes in terms of land use mixtures based on objects that are located in a given spatial unit and in terms of transit supply based on the characteristics of transit services of a given stop in a spatial unit. This paper also presents an example of the application of the method for a particular area in Katowice, Poland.

2. METHOD OF CLASSIFICATION OF SPATIAL UNITS

2.1. General scheme of the method

Application of the proposed method requires the use of spatial data that can be obtained from public databases and publicly accessible maps, such as [openstreetmap.com](https://www.openstreetmap.com). Spatial data should allow the identification of individual objects in the area of analysis and assign a specific category to these. It is also necessary to collect data about transit supply, with a particular focus on the timetables.

The proposed method consists of three main stages. The general scheme of the method is presented in Fig. 1.

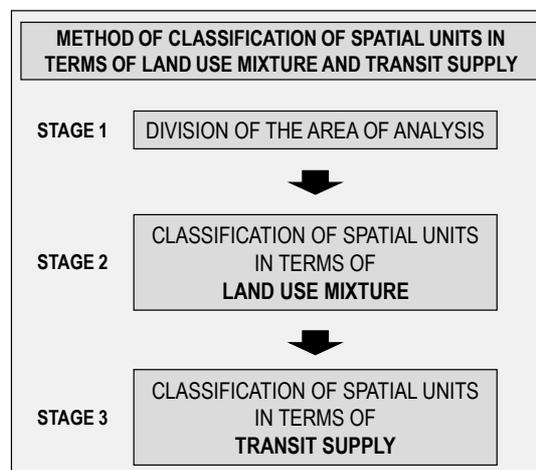


Fig. 1. General scheme of the proposed method

The first stage of the method involves the **division of the area of analysis** into smaller spatial units. This division is necessary, as most characteristics of transit performance (such as ridership) refer to a particular transit stop. Therefore, it is necessary to take into account only those characteristics of land use that influence the performance, i.e. land use objects that are in the vicinity of the stop.

Classification in terms of land use mixture, the second stage of the method, should result in assignment of a particular class of land use mixture to each spatial unit. To this end, it is necessary to identify characteristics of land use that could be factors in the process of classification, and determine the measure of land use mixture and number of classes of land use mixture.

The third general stage of the method, **the classification in terms of transit supply**, is conducted in a similar way as stage 2. It requires the completion of several steps: determination of the characteristics of transit performance that may be factors in the process of classification and determination of general measures of transit supply.

2.2. Division of the area of analysis

The first stage of the proposed method should yield a set of spatial units for further classification. To this end, several steps are required, as shown in fig. 2.

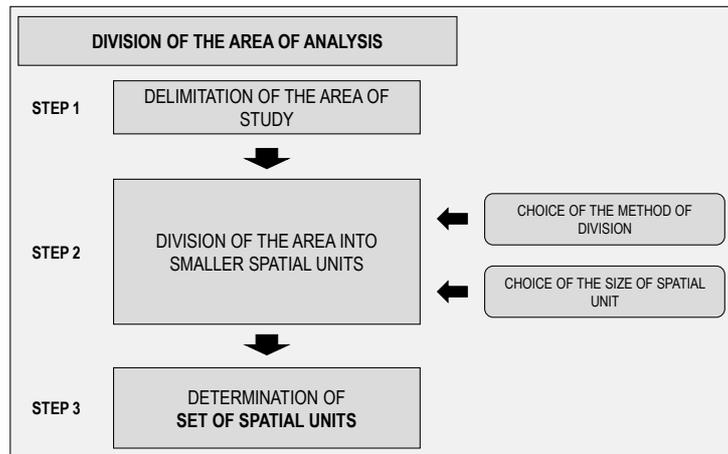


Fig. 2. Scheme of the division of the area

The delimitation of the area of analysis requires the determination of the boundaries of the whole area under study. Usually, it is the area of operation of transit, particular transit supplier, transit mode, etc. It may be delimited to the borders of territorial units, such as a town or a metropolitan area.

For the purposes of this method, it has been assumed that the whole area under study can be divided into **regular spatial units**, so-called basic fields. It requires the imposition of a regular grid over the area under study. In the case of the proposed method, it was assumed that the regular grid consists of squares. The size of the basic fields should be determined individually for each area of analysis. Smaller basic fields allow for a more detailed analysis; however, in the case of large areas, the number of basic fields may be significant. The assumption that the area should be divided into basic fields allows the use of a matrix description to identify the position of each basic field. Squares are particularly suitable for this kind of description of the whole area under study. The matrix description requires the assignment of numbers of rows and columns. The set of numbers of rows of the matrix may be written as

$$I = \{1, \dots, i, \dots, \bar{I}\} \quad (1)$$

where i – number of individual rows of the matrix that describes the analyzed area and \bar{I} – number of all rows of the matrix that describes the analyzed area. Similarly, the set of numbers of columns of the matrix may be written as

$$J = \{1, \dots, j, \dots, \bar{J}\} \quad (2)$$

where j – number of individual columns of the matrix that describes the analyzed area and \bar{J} – number of all columns of the matrix that describes the analyzed area.

Therefore, the set of basic fields may be written as

$$R = [r(i,j) : i \in I, j \in J] \quad (3)$$

where $r(i,j)$ represents a basic field that is located in i -th row and j -th column of the matrix that describes the area of analysis.

The set R will be subsequently used for classification in terms of land use mixture and transit supply. The method assumes that each basic field from this set is assigned to particular classes of land use mixture and transit supply.

2.3. Classification in terms of land use mixture

The process of classification of basic fields in terms of land use mixture requires a completion of certain steps, as shown in Fig. 3.

The classification is performed on the basis of land use characteristics in each basic field. Therefore, it is necessary to determine the characteristics to be used in the proposed method. Such characteristics should allow distinguishing different levels of land use mixture among basic fields and, moreover, they should be associated with transit ridership, as the method should enable transit-related analyses. It has been assumed that characteristics of land use can be expressed by the occurrence of objects that can be

assigned to particular groups of built-environment objects. Hence, the set of numbers of groups of built-environment objects that constitute the characteristics of land use for the process of classification may be written as

$$\mathbf{L} = \{1, \dots, l, \dots, \bar{L}\} \quad (4)$$

where l – number of individual groups of built-environment objects and \bar{L} – number of all groups of built-environment objects.

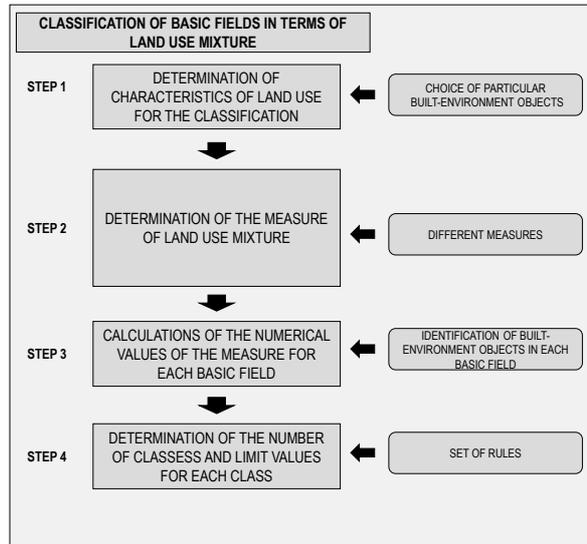


Fig. 3. Classification of basic fields in terms of land use mixture – general scheme

The determination of a complete set of all possible groups of built-environment objects is a difficult task, as some objects may be typical only for a particular region, country, or continent. They may be of great importance in such places, but including them in other areas would lead to an unnecessary increase in the time required for completion of the analysis. Therefore, the proposed method assumes the use of at least nine groups of objects; however, this set may be expanded, if necessary, after individual consideration. The nine groups that constitute set \mathbf{L} are as follows:

- 1 – residential,
- 2 – educational,
- 3 – retail and service,
- 4 – health care,
- 5 – public administration,
- 6 – catering establishments,
- 7 – sport,
- 8 – cultural and religious, and
- 9 – transport service.

Each group encompasses a set of particular objects. The identification of such particular objects should be performed individually for each region. For example, in the case of mostly suburban areas, it may be redundant to include large blocks of flats or apartment buildings in the group “residential”; however, in other areas, such objects may be common.

The next step pertains to the choice of the measure of land use mixture. For the purposes of the proposed method, it was assumed that the land use mixture in a basic field shall be represented on the basis of the number of groups of built-environment objects in the said basic field. To perform calculations on a basic field level, it is necessary to introduce a mapping f_i :

$$f_i: \mathbf{R} \rightarrow \{0,1\} \quad (5)$$

The value of f_i is calculated for each group from set \mathbf{L} and for each basic field. It takes the value of 1 if in the $r(i,j)$ -th basic field, there are built-environment objects from the l -th group and a value of 0 if

such land use objects do not exist in the $r(i,j)$ -th basic field. This method requires previous identification of all built-environment objects from groups from set L in each basic field.

The measure of a land use mixture for each basic field is therefore calculated based on the following formula:

$$\text{LMX}(r(i,j)) = \sum_{l=1}^{\bar{L}} f_l, \quad r(i,j) \in R, \quad i \in I, \quad j \in J \quad (6)$$

where: $\text{LMX}(r(i,j))$ is the numerical value of the measure of land use mixture LMX in the $r(i,j)$ -th basic field.

Calculations of numerical values of the LMX measure should be conducted for each basic field. In the case of set L that was proposed in the method, the value of \bar{L} equals 9. However, in the case of expanded sets, this value may be different. Subsequently, it is necessary to determine the number of classes of basic fields in terms of land use mixture. On this basis, limit values for each class are identified and each basic field is classified into one class.

In the case of 9 groups of built-environment objects, the LMX measure may vary from 0 (no objects from set L in the basic field) to 9 (objects from each group are present). There are different rules pertaining to the process of determination of the number of classes and limit values. This number should be set based on the maximal and minimal values of the LMX measure for the whole area. In areas characterized by low levels of land use mixture, it may be reasonable to treat each value as a separate class; however, in the case of more distinguished regions, it may be necessary to create classes containing more than one value of the said measure.

2.4. Classification in terms of transit supply

Classification of basic fields in terms of transit supply allows comparison of basic fields that are similar to the level of service that is provided. Better service usually leads to higher levels of ridership and comparison of significantly different basic fields in terms of transit supply could lead to false conclusions. The steps necessary for the classification in terms of transit supply are presented in fig. 4.

The first step of the process of classification of basic fields in terms of transit supply requires the identification of characteristics of transit that should be factors in the classification. Such characteristics should pertain to different aspects of the operation of transit to provide a comprehensive analysis. The set of numbers of such characteristics of transit supply may be written as

$$T = \{1, \dots, t, \dots, \bar{T}\} \quad (7)$$

where t – number of individual characteristics of transit supply and \bar{T} – number of all characteristics of transit supply.

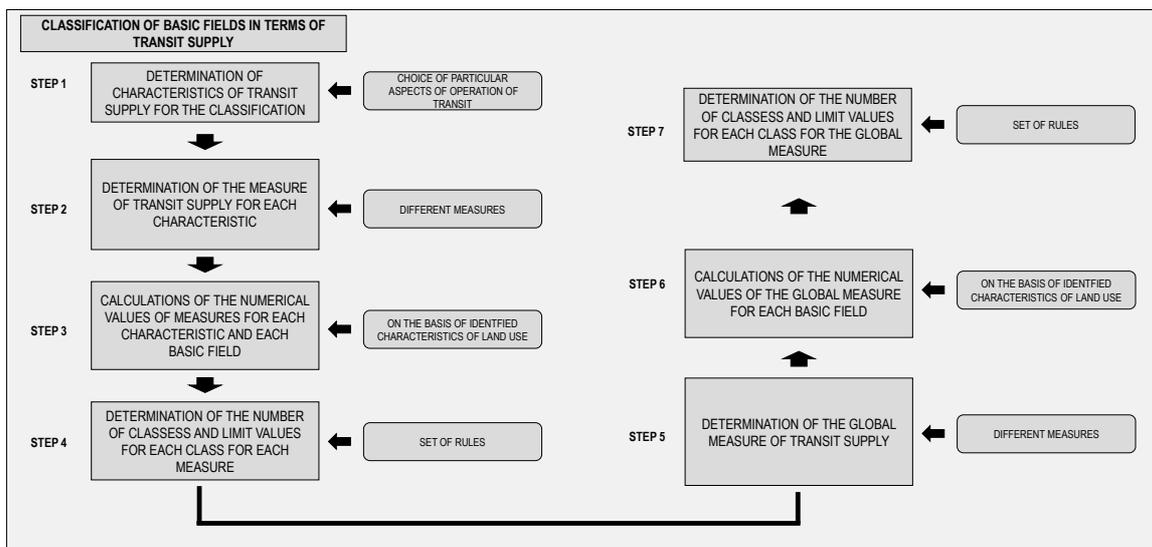


Fig. 4. Classification of basic fields in terms of transit supply – general scheme

For the purposes of the method, three characteristics of transit supply have been determined: 1 – number of transit lines, 2 – frequency of service, and 3 – range of service. Each characteristic pertains to a different aspect of the operation of transit, and therefore, should be expressed by separate measures. Subsequently, all measures are used to create the global measure of transit supply.

To calculate the numerical values of each measure, it is necessary to create the set of transit stop stations in each basic field. Stop station is understood as a basic element of a transit stop.

The set of numbers of transit stop stations in an individual basic field may be written as

$$\mathbf{S}(r(i,j)) = \{1, \dots, s(r(i,j)), \dots, \overline{S(r(i,j))}\}, r(i,j) \in \mathbf{R}, i \in \mathbf{I}, j \in \mathbf{J} \quad (8)$$

where

$s(r(i,j))$ – number of individual transit stop stations in the $r(i,j)$ -th basic field and

$\overline{S(r(i,j))}$ – number of all transit stop stations in the $r(i,j)$ -th basic field.

It is also required to identify all transit lines in the area under study and formulate a set of their numbers as follows:

$$\mathbf{N} = \{1, \dots, n, \dots, \overline{N}\} \quad (9)$$

where n – number of individual transit line in the area of analysis and \overline{N} – number of all individual transit lines in the area of analysis.

For the calculations of measures pertaining to the range of service, the set of all municipalities in the area of study should be determined. It may be written as

$$\mathbf{M} = \{1, \dots, m, \dots, \overline{M}\} \quad (10)$$

where m – number of individual municipalities in the area of analysis and \overline{M} – number of all individual municipalities in the area of analysis.

Also, it is necessary to determine the set of districts in the municipality that was chosen for the analysis. The set of numbers of districts may be written as

$$\mathbf{D} = \{1, \dots, d, \dots, \overline{D}\} \quad (11)$$

where d – number of individual districts in the area of analysis and \overline{D} – number of all individual districts in the area of analysis.

On this basis, four measures of transit supply have been determined:

measure z1 – number of transit lines in the basic field,

measure z2 – average frequency of service in the basic field during the rush hour period,

measure z3 – number of different municipalities that may be traveled to from a particular basic field without the need for transfer, and

measure z4 – number of different districts that may be traveled to from a particular basic field without the need for connection.

For the purposes of calculation of numerical values of measure z1, it is necessary to introduce the mapping g :

$$g: \mathbf{S}(r(i,j)) \times \mathbf{N} \rightarrow \{0,1\} \quad (12)$$

The mapping assigns to each element of Cartesian product $\mathbf{S}(r(i,j)) \times \mathbf{N}$ values 0 or 1. The value of 1 is assigned if the n -th line serves the $s(r(i,j))$ -th transit stop station and the value of 0 is assigned if the n -th line does not serve the $s(r(i,j))$ -th transit stop station.

Subsequently, the number of transit lines $NS(s(r(i,j)))$ at an individual transit stop station is calculated based on the following formula:

$$NS(s(r(i,j))) = \sum_{n=1}^{\overline{N}} g_n(s(r(i,j))), s \in \mathbf{S}(r(i,j)), r(i,j) \in \mathbf{R}, i \in \mathbf{I}, j \in \mathbf{J} \quad (13)$$

By summation of the values of NS for each transit stop station, in particular, the basic field, the value of measure z1 for that basic field may be obtained according to the following formula:

$$z1(r(i,j)) = \sum_{s(r(i,j))=1}^{\overline{S(r(i,j))}} NS(s(r(i,j))) - v(r(i,j)), s \in \mathbf{S}(r(i,j)), r(i,j) \in \mathbf{R}, i \in \mathbf{I}, j \in \mathbf{J} \quad (14)$$

where $z1(r(i,j))$ is the number of transit lines in the entire basic field and $v(r(i,j))$ is a corrective variable that reflects the additional number of transit lines as a recurrence of the same transit line on multiple transit stop stations.

Calculation of numerical values of measure $z2$ requires the introduction of the mapping h

$$h: \mathbf{S}(r(i,j)) \times N \rightarrow \mathbb{N} \quad (15)$$

The mapping assigns to each element of Cartesian product $\mathbf{S}(r(i,j)) \times N$ a number from the set of natural numbers. The value of h indicates the number of courses of the n -th line from the $s(r(i,j))$ -th transit stop station.

Hence, the number of courses from an individual transit stop station in the rush hour period is calculated based on the following formula:

$$FS(s(r(i,j))) = \frac{\sum_{n=1}^{\bar{N}} h_n(s(r(i,j)))}{a}, \quad s \in \mathbf{S}(r(i,j)), r(i,j) \in \mathbf{R}, i \in \mathbf{I}, j \in \mathbf{J} \left[\frac{1}{h} \right] \quad (16)$$

where:

$FS(s(r(i,j)))$ is the number of all courses in the rush hour period from the $s(r(i,j))$ -th transit stop station and

a – the duration of the rush hour period [h].

On this basis, the value of measure $z2(r(i,j))$, which is the average number of courses from a given basic field in the rush hour period, is calculated based on the following formula:

$$z2(r(i,j)) = \frac{\sum_{s(r(i,j))=1}^{\bar{s}(r(i,j))} FS(s(r(i,j)))}{\bar{s}(r(i,j))}, \quad s \in \mathbf{S}(r(i,j)), r(i,j) \in \mathbf{R}, i \in \mathbf{I}, j \in \mathbf{J} \left[\frac{1}{h} \right] \quad (17)$$

The last two measures pertain to the range of transit service in the area under study. The first measure requires the introduction of the mapping k :

$$k: \mathbf{R} \times \mathbf{M} \rightarrow \{0,1\} \quad (18)$$

The mapping assigns to each element of Cartesian product $\mathbf{R} \times \mathbf{M}$ value 0 or 1. Value 1 is assigned if there is a direct connection between the m -th municipality in the area of analysis and the $r(i,j)$ -th basic field, whereas value 0 is assigned if this connection does not exist.

Subsequently, the value of measure $z3(r(i,j))$, which is the number of municipalities in the area under study that has a direct connection with the $r(i,j)$ -th basic field for each basic field, is calculated as follows:

$$z3(r(i,j)) = \sum_{m=1}^{\bar{M}} k_m(r(i,j)), \quad r(i,j) \in \mathbf{R}, i \in \mathbf{I}, j \in \mathbf{J} \quad (19)$$

Measure $z4$ is calculated in an analogical way. First, the mapping b is introduced as follows:

$$b: \mathbf{R} \times \mathbf{D} \rightarrow \{0,1\} \quad (20)$$

The mapping assigns to each element of Cartesian product $\mathbf{R} \times \mathbf{D}$ value 0 or 1. Value 1 is assigned if there is a direct connection between the d -th district in the area of analysis and the $r(i,j)$ -th basic field, whereas value 0 is assigned in the opposite case.

The value of measure $z4$ for each basic field is calculated as follows:

$$z4(r(i,j)) = \sum_{d=1}^{\bar{D}} k_d(r(i,j)), \quad r(i,j) \in \mathbf{R}, i \in \mathbf{I}, j \in \mathbf{J} \quad (21)$$

where $z4(r(i,j))$ is the number of districts in the area under study that has a direct connection with the $r(i,j)$ -th basic field.

After performing calculations of all four measures of transit supply for each basic field, the next step is the classification of each basic field into appropriate classes. For the purposes of determination of global measures of transit supply, it is required that all measures have the same number of classes. The number of classes and limit values for each class are determined individually after performing the calculations. After classification, each basic field is assigned to four classes. Classes represent the ascending order of the level of service; hence, the higher the number of the class, the higher the level of transit supply. The global measure of transit supply may therefore be written as

$$TSX(r(i,j)) = c1(z1(r(i,j))) + c2(z2(r(i,j))) + c3(z3(r(i,j))) + c4(z4(r(i,j))) \quad (22)$$

where $TSX(r(i,j))$ is the value of measure TSX in the $r(i,j)$ -th basic field and $c1, c2, c3, c4$ represent the number of class for each measure.

After the calculation of the values of global measures, each basic field should be classified into one, final, class of transit supply. The number of classes of the measure TSX should be the same as the number of classes for each characteristic, and limit values should be determined individually.

3. APPLICATION OF THE METHOD

The proposed method has been used for a chosen area in Katowice, a city in southern Poland. Katowice has a population of c.a. 290 000 inhabitants, whereas the whole metropolitan area is inhabited by more than 2,2 million people [24]. Transit in Katowice and the whole Metropolis GZM is organized by ZTM (Metropolitan Transport Authority).

According to figures 1 and 2, the first step of the method is establishment of the boundaries of the area under study. The area of analysis has been allocated in a central part of Katowice.

During the next step of the application of the method, the area was divided into smaller units – regular basic fields with the shape of a square. The side of a square was determined to be 150 meters. It allowed coverage of the whole area under study with identical basic fields. Each basic field was assigned numbers of a row and a column from sets I and J . This method of division resulted in 15 rows and 15 columns in each set. As a result, the set R was created, consisting of 225 basic fields. The result of the division with an imposition of a regular grid is shown in fig. 5.



Fig. 5. Division of the area into basic fields

The second stage of the method begins with the determination of the characteristics of land use that should be used for the classification. In the presented case study, it was decided that there was no need to expand the set L with any additional groups of built-environment objects; thus, 9 groups were used. Measure LMX was used to perform necessary calculations for each basic field. Data for the classification during stage 2 were obtained from OpenStreetMap [25].

Calculations were preceded by identification of all built-environment objects from groups 1 to 9 in each basic field. For example, in one basic field, there were 17 objects from the group “residential”, 1 object from the group “health care,” and 1 object from the group “educational”. Therefore, the value of f_i for each group was as follows: $f_1=1, f_2=1, f_3=0, f_4=1, f_5=0, f_6=0, f_7=0, f_8=0, and f_9=0$. Hence, the value of measure LMX for the analyzed basic field may be calculated as $LMX=\sum_{i=1}^9 f_i=3$.

This means that the value of the measure of land use mixture in that particular basic field equals 3. Similar processes of identification of built-environment objects and calculations were conducted for each basic field from set R . After the calculations, each basic field was assigned a value of measure LMX. The maximal value of LMX was 6, and the minimal value was 0. Hence, it was decided that the number of classes of land use mixture shall be 7, and each value should constitute a separate class (LMX = 0 – class 1, LMX = 1 – class 2, etc.). The results of the calculations are presented in Fig. 6.

The first step of the third stage of the method, which is classification in terms of transit supply, requires the choice of the characteristics of transit supply. It was decided that the set T , containing three characteristics, should not be expanded. Four measures, $z_1, z_2, z_3,$ and z_4 , were used for the calculations.

The example of the performed calculations will be presented for one chosen basic field. Data for the classification during stage 3 were obtained from the website of the Metropolitan Transport Authority [26] and OpenStreetMap [25].

First, all transit lines, municipalities, and districts in the area of analysis were identified to create sets $N, M,$ and D . Subsequently, the set $S(r(i,j))$ for the chosen basic field was determined. In the chosen basic field, there were two stop stations, which means that set $S(r(i,j))$ contained two elements: $S(r(i,j))=\{1,2\}$. To calculate the value of measure z_1 , the mapping g was performed. Then, for each

stop station in the field, the value of $NS(s(r(i,j)))$ was calculated. NS for each stop station equaled 2, and since they were the same transit lines, the value of measure $z1$, after inclusion of the corrective variable $v(r(i,j))$, also equaled 2. Calculations of measure $z2$ required performing of the mapping h .

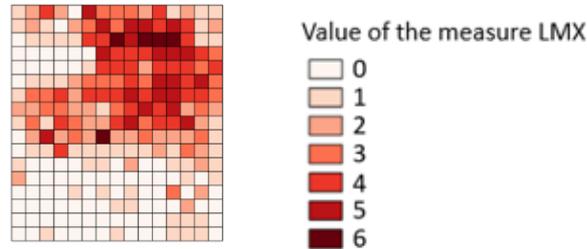


Fig. 6. Results of calculations of measure LMX

Then, the value of $FS(s(r(i,j)))$ was calculated, with $a=1$ [h]. Conclusively, the value of $z2=16$. In the case of measure $z3$, all transit lines in this basic field serve just one municipality; therefore, the value of measure $z3=1$. The value of measure $z4$ was equal to 4 because both lines in the field had similar routes and served the same four districts within the city.

Such calculations were performed for each basic field with a transit stop station separately. Subsequently, number of classes was established for all measures. It was decided that there shall be 4 classes for each measure. The limit values for each measure are presented in table 1.

Table 1

Limit values for classes of values of given transit supply measures

	Measure $z1$	Measure $z2$	Measure $z3$	Measure $z4$
Class 1	less than 5	less than 20/h	less than 5	less than 5
Class 2	5 to 10	20/h to 40/h	5 to 10	5 to 10
Class 3	10 to 15	40/h to 60/h	10 to 15	10 to 15
Class 4	more than 15	more than 60/h	more than 15	more than 15

Each basic field was assigned to one class for each measure. The results of this classification are presented in fig. 7a-7b.

The analyzed basic field was classified into class 1 for each measure. This means that the global measure for transit supply for that basic field was calculated as follows: $TSX = c1(z1(r(i,j))) + c2(z2(r(i,j))) + c3(z3(r(i,j))) + c4(z4(r(i,j))) = 1 + 1 + 1 + 1 = 4$. Similarly, the value of the global measure was calculated for all other basic fields. The number of classes, according to the proposed method, had to be the same as for measures $z1$ to $z4$ and equaled 4. Limit values were established as follows: class 1: $<0 - 4>$, class 2: $(4 - 8>$, class 3: $(8 - 12>$, and class 4: $(12 - 16>$. The results of the classification are presented in fig. 7e.

Each basic field in the area of analysis was assigned to one class of land use mixture and one class of transit supply, according to the proposed method.

4. CONCLUSIONS

To realize goals of sustainable mobility, it is of great importance to shape the transit system in such a way that it is adjusted to the needs of its users. In the case of transit, the level of usage is usually expressed by a ridership at a stop level; hence, multiple studies have focused on the identification of factors that influence the ridership. Among different factors, research indicates that land use mixture may be significant, although its impact is not clear. Therefore, it is necessary to study the relationship of this factor with transit effectiveness. Such analyses, however, require the determination of a level of

land use mixture of a certain area. Land use mixture should also be associated with objects that may generate demand for transit services. Ridership depends on transit supply; thus, spatial units should be compared within the same level of supply.

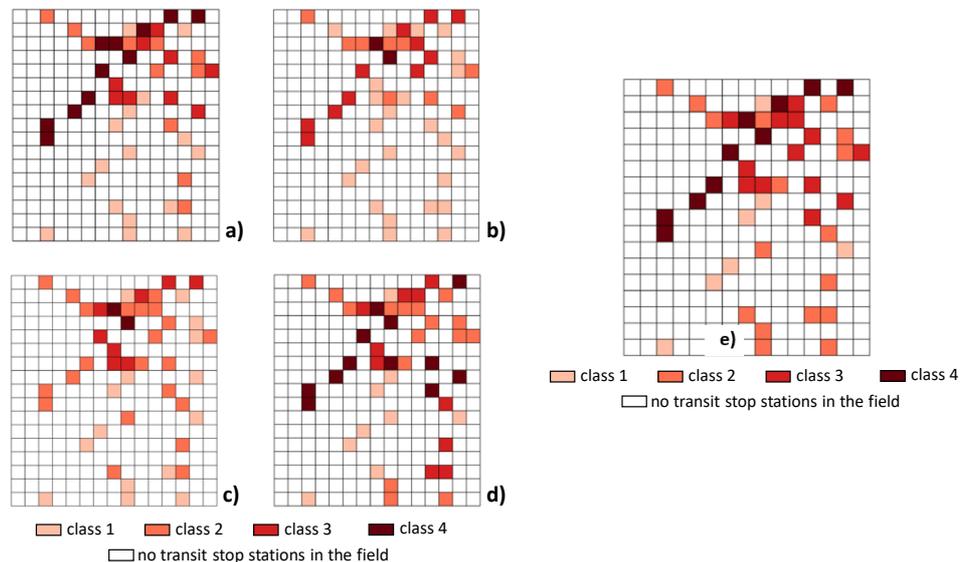


Fig. 7. Classification of the basic field for each measure of transit supply: a) measure z1, b) measure z2, c) measure z3, d) measure z4, and e) global measure of transit supply TSX

Hence, the main aim of this paper was to propose a method of classification of spatial units in terms of land use mixture and transit supply for transit-related analyses. The method assumes the use of spatial data and data from timetables. The area of analysis is divided into smaller spatial units (basic fields) through a regular tessellation. In the proposed method, different characteristics of land use (related to the built environment) and transit supply are used as factors in the process of classification of basic fields. In the case of land use mixture, the method allows determination of the level of mixture taking into account built-environment objects that are associated with transit needs. For transit supply, the characteristics of transit service are used, and the method allows classification of spatial units in a general way using measures pertaining to different aspects of operation of transit systems, which are often difficult to compare.

Application of the method allowed the classification of 255 basic fields in Katowice into classes of land use mixture and transit supply. The presented method of classification may be useful in transit-related analyses, such as analysis of the influence of land use mixture on ridership for a given level of transit supply.

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