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Piotr SOCZÓWKA[1]*, Renata ŻOCHOWSKA[2]

THE CLASSIFICATION OF RAILWAY STOPS AND STATIONS IN TERMS OF LAND USE STRUCTURE IN THEIR SURROUNDINGS

Summary. Ensuring the high accessibility of railway stops and stations is essential to effective transport systems in urban areas. There are different ways to analyze accessibility at the station level. In this paper, it has been assumed that railway stops and stations should be located in places with significant demand for passenger rail transport characterized by a highly dense and diversity-rich land use structure. Therefore, the presented classification uses data on the built environment in the surroundings of these elements of the railway infrastructure, with particular attention to the type of each building. The analysis was performed for the Metropolis GZM area. Based on the gathered spatial data, railway stops and stations in the aspect of the density and diversity of the built environment in their vicinity were classified. This classification can be applied to the assessment of accessibility.

1. INTRODUCTION

Rail transport is among the most versatile branches of transport. It may be effectively used for transporting people and transport of goods [1,2]. In the case of passenger transport, several characteristics stand out from other means of transport. Trains can transport many passengers, reach high speeds, and are eco-friendly [3, 4]. Due to the separation of railway infrastructure from road traffic, trains are not prone to congestion. Railway transport is also safer than road transport, considering both accidents and fatalities [5, 6]. However, it requires a more enhanced infrastructure [7]. Railway stations require more space than bus stops and may not be in the same neighborhood as the built environment for safety and comfort reasons. Therefore, in large metropolitan areas, railways should constitute the backbone of transit [8, 9], allowing people to quickly travel between major locations. Other subsystems should play supplementary roles, enabling people to travel to and from railway stations or in areas with no railway network [10, 11]. In a transit system organized in such a way, the density of the railway network is usually significantly lower than the road and street network. Therefore, the proper location of any railway infrastructure is of great importance [12].

The locations of railway stations should allow for the appropriate level of safety, the standard of service for passengers, and the well-being of the inhabitants of the vicinity. On the other hand, to encourage potential passengers, railway stops and stations should be highly accessible. Accessibility is a widely used term; however, it is difficult to define it in an unambiguous way [13, 14]. One of the first definitions of this term, proposed by Hansen in 1959, is 'the potential for opportunities of interactions' [15]. Other approaches emphasize the involvement of two essential elements: the location on the surface relative to suitable destinations and the characteristics of the transport network [16]. According to [17, 18], accessibility can be understood as the ease with which people can reach certain destinations. It can also be defined as a representation of the potential of users to perform their activities [19]. Moreover,

[1] Silesian University of Technology; Krasińskiego 8, 40-019 Katowice, Poland; email: piotr.soczowka@polsl.pl; orcid.org/0000-0002-8514-4155
[2] Silesian University of Technology; Krasińskiego 8, 40-019 Katowice, Poland; email: renata.zochowska@polsl.pl; orcid.org/0000-0002-8087-3113
* Corresponding author. E-mail: piotr.soczowka@polsl.pl

accessibility can be treated as the main product of transport systems, which is one determinant of one location's advantages over others [20].

There are many ways to measure accessibility. According to [21-23], accessibility measures can be based on infrastructure, location, individual level, and utility. Infrastructure-based measures allow analyses of the performance of transport infrastructure. Measures related to location and the individual level enable the analysis of the range of available possibilities concerning their distribution in space and the travel impedance between origin and destination. Meanwhile, utility-based measures are used to analyze the benefits of the individuals derived from the land-use transport system. In turn, in [24], the authors suggest five methods for measuring accessibility: accessibility measured by infrastructure factors, distance, cumulative accessibility, potential accessibility, and personalized accessibility.

A high level of accessibility is among the most important and most common demands of transit system passengers. Therefore, it is essential to identify which elements of the railway infrastructure are difficult to access and implement solutions to increase accessibility. However, the land use structure in the area served by passenger rail transport is heterogeneous, which also affects the transport needs of residents. Therefore, when assessing accessibility, spatial differences in the vicinity of railway stops and stations should be considered [25-27]. Thus, the classification of such point elements of the railway infrastructure in terms of land use structure is an important stage in accessibility assessments [28-32]. Dividing the railway stops and stations into groups with similar spatial characteristics allows independent analyzes to be conducted for each group. Therefore, this paper proposes a classification of railway stops and stations based on the built environment in their vicinity, which allows one to compare the stations in terms of the density and diversity of the land use structure, as well as to identify those that are characterized by a low level of that feature. A large metropolitan area in southern Poland has been chosen as the area of study.

The article begins with an introduction that describes the research problem and the purpose of the study. The second section contains details about the method of the study. Descriptions of the area under study and the railway network in the analyzed area are presented in the third section. The fourth section encompasses the results of the analysis, and the last section covers conclusions and propositions of future work.

2. METHODOLOGY

The proposed methodology assumes that the classification of the railway stops and stations is based on the description of the land use structure in their vicinity. The main problem is the selection of the types of objects in the built environment when separating groups. Each facility is associated with an activity system represented by a set of its users' individual socio-economic needs. Therefore, it was assumed that the numbers of particular types of buildings could be a proxy for specific urban activities. These activities result in individual transport needs and travel behavior in particular territorial units of the area [33-35]. Thus, they describe the area in terms of its mobility characteristics. The locations of objects related to human activity and places of residence affect the transport demand and its spatial and temporal distribution.

The general scheme of the method is presented in Fig. 1. The method consists of four main stages:

- analysis of the land use structure in the vicinity of railway stops and stations,
- selection of the variables describing the land-use structure,
- classification of railway stops and stations by type of land use structure, and
- analysis of railway stations and stops.

Before the analytical part of this work is presented, the spatial scope of the analyzed area should be determined. This requires the area to be appropriately delimitated. The description of the land use structure consists of determining the variable that could affect the process of generating transport demand. The railway stops and stations in the study area should also be identified when determining the spatial scope.

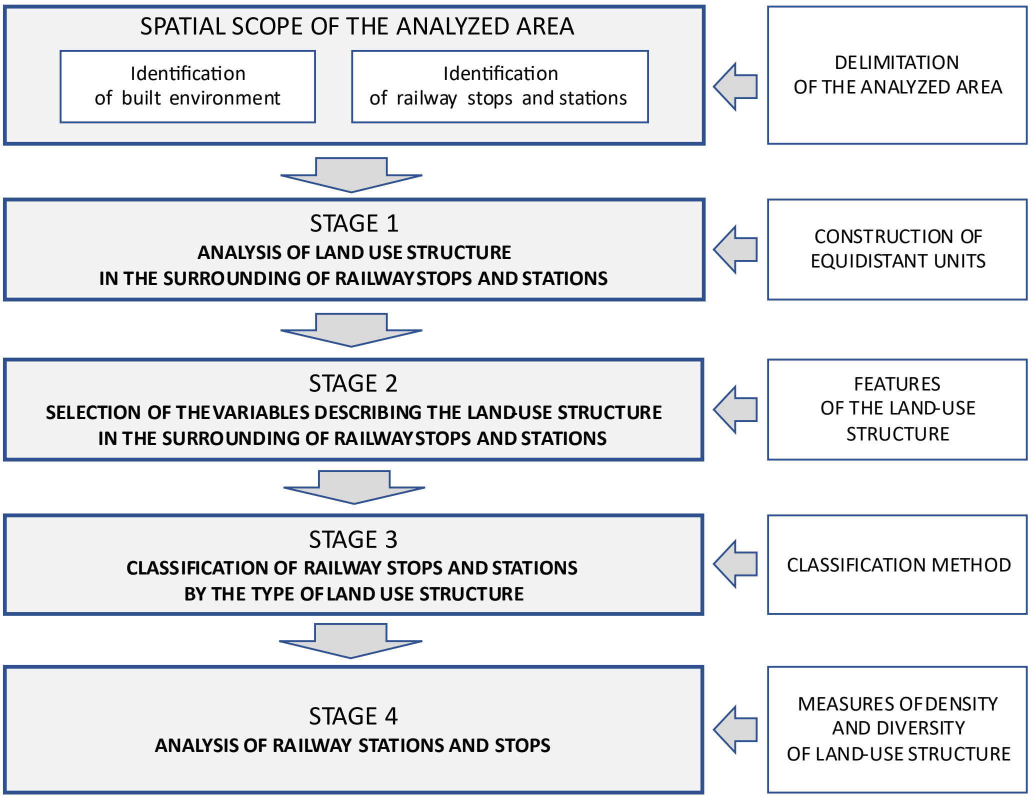

Fig. 1. General scheme of the method for classifying railway stops and stations

When analyzing accessibility, it is crucial to choose the method of designing the catchment area delimited by lines of equal distance. For individual objects, the impact areas based on equidistant units (which are understood as lines connecting points with the same distance from this object) are often determined. Such an approach has been adopted in this method. In stage 1, equidistant units with a radius of 800 m have been built around each railway stop and station. The method is based on a simplified Euclidean distance without considering the road and street network. The line created this way is the basis for determining the vicinity of the railway stop and station. At this stage, the built environment within the defined area is also identified.

In the proposed method, the description of the land use structure has been adopted, which considers the variables related to different types of buildings and facilities with different functionalities. The variables used are described in Tab. 1.

Table 1

Variables describing the land use structure in the vicinity of the railway stops and stations

Variable	Description of the variable
X_1	number of residential buildings
X_2	number of office buildings
X_3	number of commercial and service buildings
X_4	number of industrial buildings and warehouses
X_5	number of cultural buildings
X_6	number of educational buildings
X_7	number of health care buildings
X_8	number of sports and recreational objects
X_9	number of farm buildings

In stage 2, based on previously defined types of objects, appropriate numerical values of variables characterizing land-use structure are assigned to individual railway stations and stops. The assignment of these values is the basis for classifying the identified elements of the railway infrastructure.

Complex socio-economic phenomena (expressed as a large set of variables) can be described and grouped using various taxonomic methods. The classification procedure consists of selecting homogeneous subgroups in a set of multi-feature objects. In the method used in stage 3, the classification has been performed using the Ward agglomeration method, according to which each object initially constitutes a separate group, and then the number of groups is successively reduced by combining them into higher-order groups [36-38]. The process of combining objects ends when one group consisting of a set of all objects is obtained.

With this approach, each railway stops and station located in the studied area has been assigned to one class based on the values of variables describing the land use structure. The elements of the railway infrastructure belonging to a class should be significantly similar in terms of previously defined characteristics (i.e., there should be low intra-class variance). The classification should guarantee a large variation for objects belonging to different classes (i.e., there should be large variance between classes) [36-38]. Then, in stage 4, individual railway stops or stations within each class were analyzed according to specific measures. The proposed method uses two measures:

- $W1(i,j)$, which denotes the density of objects of the i-th type (variable X_i in Table 1) in the vicinity (limited by an equidistant unit with a radius of 800 m) of the j-th railway stop or station. This measure is determined according to the formula:

$$W1(i,j) = \frac{X_{i,j}}{P_{R=800}} \qquad \left[\frac{1}{\mathrm{km}^2}\right] \tag{1}$$

where $X_{i,j}$ – the value of the variable X_i for the j-th railway stop or station; $P_{R=800}$ – the area of the equidistant unit with a radius of 800 m

- $W2(i,j)$, which denotes the percentage share of the number of objects of the i-th type (variable X_i in Table 1) in the vicinity of the j-th railway stop or station. This measure is determined according to the following formula:

$$W2(i,j) = \frac{X_{i,j}}{\sum_{i=1}^{9} X_{i,j}} \cdot 100 \qquad [\%] \tag{2}$$

These measures have been determined for each type of variable described in Table 1 for each railway stop and station. Considering the classification of railway infrastructure carried out in stage 3, the average values of the measures for each class have been determined based on the formulas below:

$$W1^{\mathrm{avg}}(i,k) = \frac{\sum_{j \in A(k)} X_{i,j}}{|A(k)| \cdot P_{R=800}} \qquad \left[\frac{1}{\mathrm{km}^2}\right] \tag{3}$$

and

$$W2^{\mathrm{avg}}(i,k) = \frac{\sum_{j \in A(k)} X_{i,j}}{\sum_{j \in A(k)} \sum_{i=1}^{9} X_{i,j}} \cdot 100 \qquad [\%] \tag{4}$$

where $A(k)$ stands for the set of railway stops and stations of the k-th class, and $|A(k)|$ is the number of elements in the set.

In the comparative analysis, the measures values of the obtained measures for railway stations and stops belonging to different classes are compared.

3. RESEARCH AREA

The classification of railway infrastructure has been carried out for the area of the Metropolitan Association of Upper Silesia and Dąbrowa Basin (Metropolis GZM). This is a metropolis in Poland that is made up of 41 municipalities with very different levels of socio-economic development and land use structure. This area is inhabited by 2.3 million people, and its total area is 2500 square kilometers. About 240,000 companies and enterprises operate in the GZM area, producing approximately 8% of the GDP of the entire country [39]. Fig. 2 shows the studied area on the background of Poland and the Silesian Voivodeship.

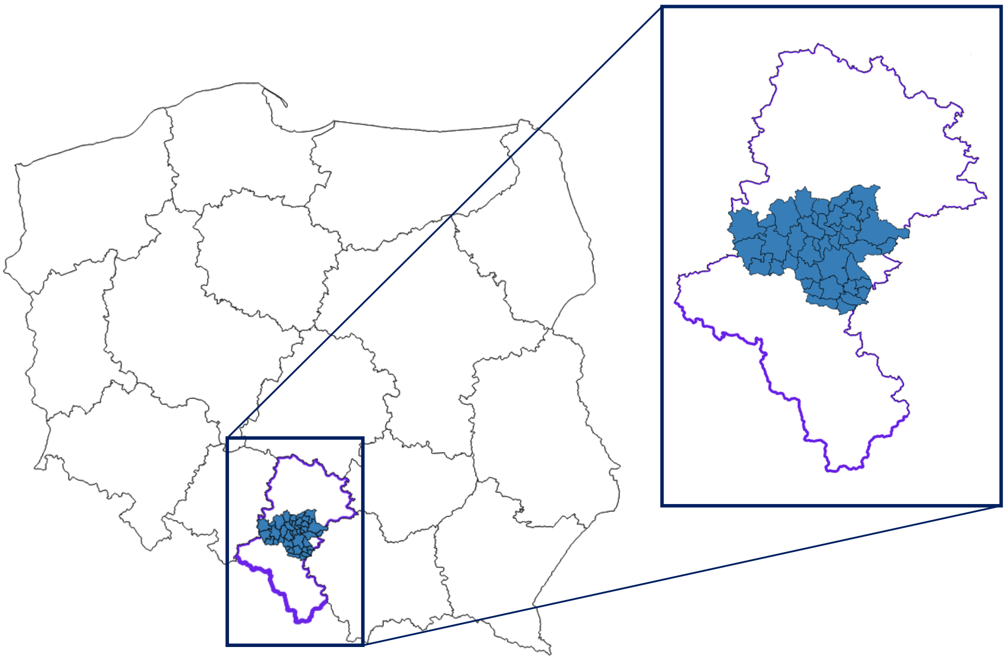

Fig. 2. The area of study on the background of Poland and Silesian Voivodeship

The railway network serving passenger transport is located only in 26 municipalities of the GZM (i.e., 63.4% of all administrative units belonging to this metropolis). In terms of area, they cover 68.6% of the total area of the GZM; in terms of the number of inhabitants, they cover approximately 85.1%. Fig. 3. presents the studied area and indicates the municipalities that have access to a railway network with passenger transport services. The specification of municipalities with railway stops and stations for which the classification has been carried out is included in Table 2.

As presented in Table 2, most administrative units have no more than three railway stops and stations. Larger numbers of such objects are observed mostly in units with greater areas (i.e., Katowice, Dąbrowa Górnicza, and Sosnowiec). In most units with more than 100,000 inhabitants, there are at least three railway stops or stations.

Table 2

Information on the administrative units analyzed (as of 30 July 2020)

No.	Administrative unit	Number of railways stops and stations	Number of inhabitants	Area [km^2]
1.	Będzin	3	56,191	37
2.	Bieruń	1	19,457	40
3.	Bytom	3	164,447	69
4.	Chełm Śląski	1	6356	23
5.	Chorzów	3	107,443	33
6.	Dąbrowa Górnicza	7	118,899	189
7.	Gierałtowice	1	12,228	38
8.	Gliwice	3	178,186	134
9.	Imielin	1	9274	28
10.	Katowice	8	291,774	165
11.	Knurów	1	38,004	34
12.	Kobiór	1	4923	48
13.	Łaziska Górne	2	22,187	20
14.	Mikołów	2	41,078	79
15.	Mysłowice	4	74,601	66

No.	Administrative unit	Number of railways stops and stations	Number of inhabitants	Area [km^2]
16.	Pyskowice	1	18,450	31
17.	Radzionków	2	16,906	13
18.	Ruda Śląska	2	137,030	78
19.	Rudziniec	3	10,643	159
20.	Sławków	1	6991	37
21.	Sosnowiec	5	198,996	91
22.	Świerklaniec	1	12,504	45
23.	Świętochłowice	1	49,363	13
24.	Tarnowskie Góry	1	61,756	84
25.	Tychy	6	127,307	82
26.	Zabrze	1	171,691	80
Total		65	1,956,685	1716

Source: [40]

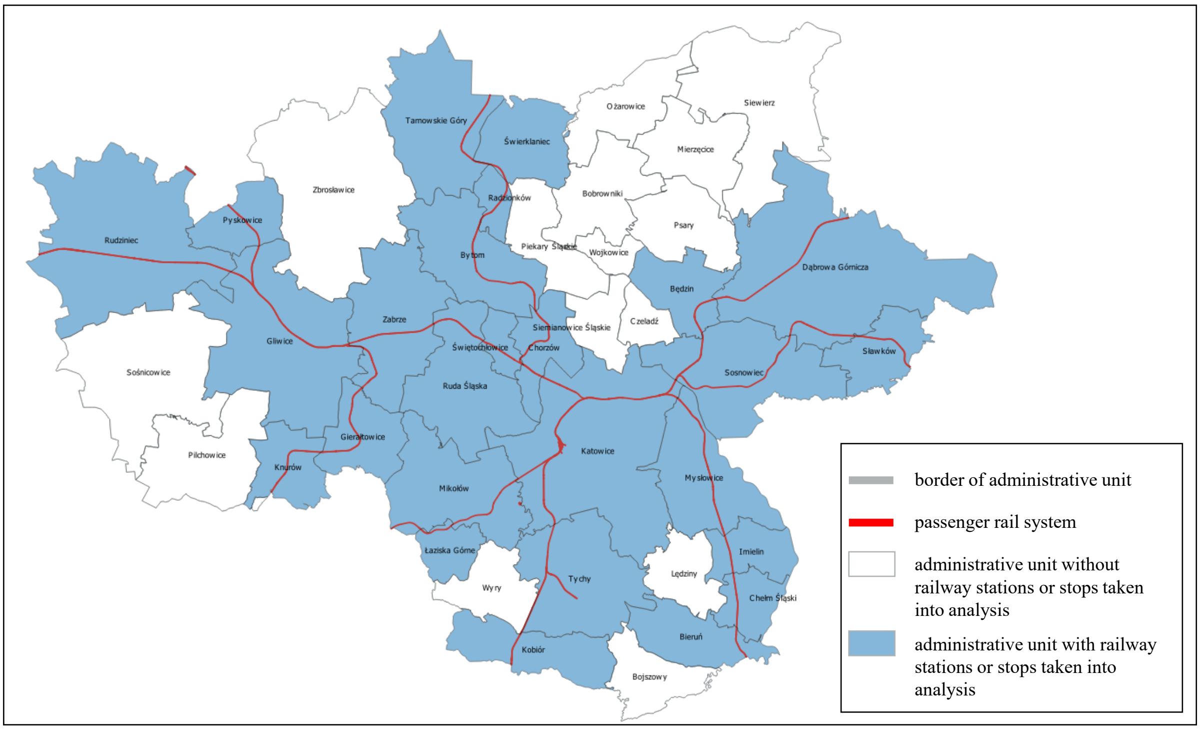

Fig. 3. The area of Metropolis GZM

4. RESULTS OF THE ANALYSIS

For the first stage of the analysis, it was essential to gather information about railway stops and stations in the area of analysis, as well as the characteristics of land use in their vicinity. Subsequently, the classification of railway infrastructure was carried out according to the type of land use. Fig. 4 presents a classification tree of the railway stops and stations in the study area.

Fig. 4 shows a visible division of all analyzed stops and stations into two classes. However, four classes were distinguished to make the analysis more detailed. Each station was assigned to one of these four classes (Table 3).

According to Table 3, the highest number of stops and stations (29) was assigned to class 2. There are 21 stops and stations in class 3 and 14 in class 4. Only one station – Katowice, which is the most important passenger station in Metropolis GZM—was assigned to class 1.

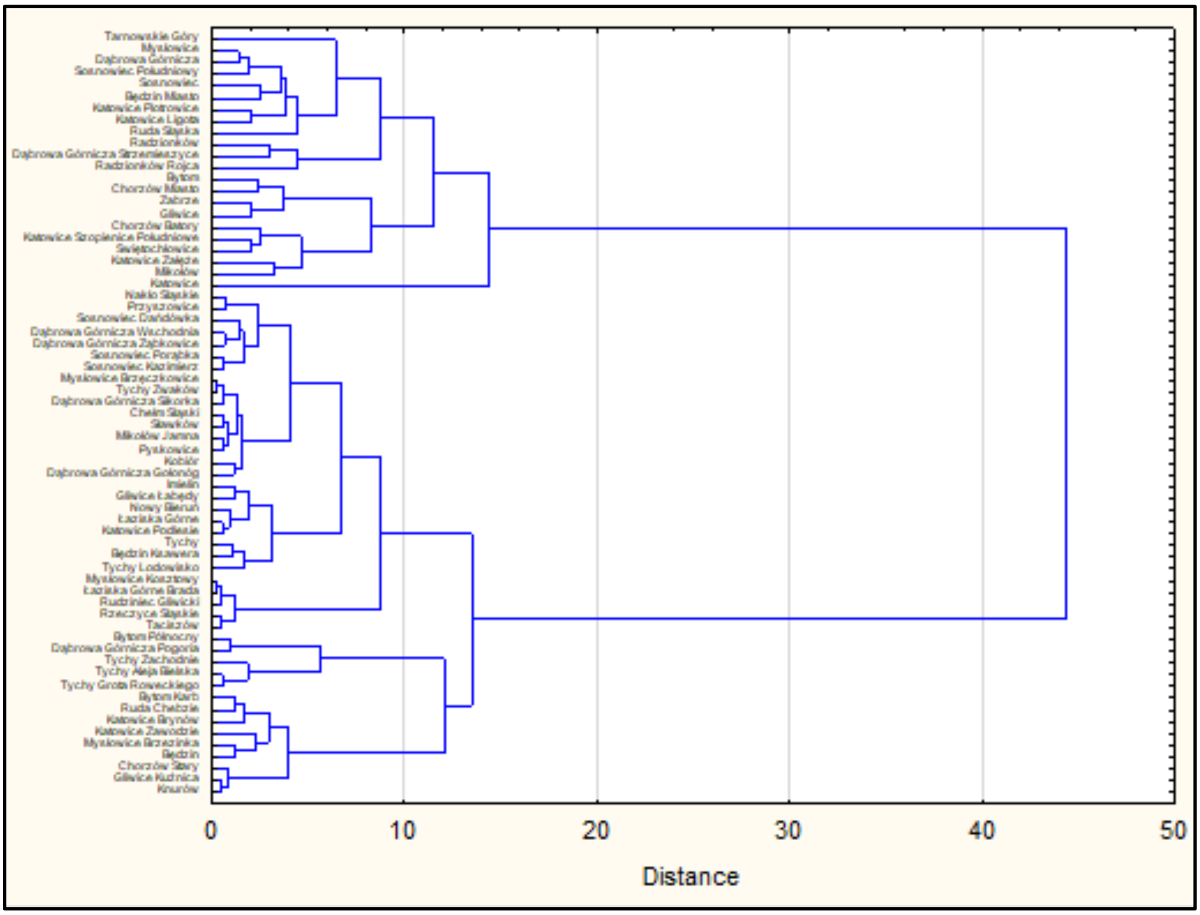

Fig. 4. Classification tree of the railway stops and stations in the GZM

The proposed method assumes the use of nine variables for classification purposes. Each variable represented the number of objects of a built environment of a different type. Table 4 contains numerical values of the following characteristics of the land use structure in the vicinity of the railway stop and station for each class: the average number of built environment objects, the average density of built environment objects ($W1^{\mathrm{avg}}(i,k)$), and the percentage share of the number of built environment objects ($W2^{\mathrm{avg}}(i,k)$).

Table 3

Assignment of railway stations and stops

Class	Name of the railway stop or station
1	Katowice
2	Będzin Ksawera, Chełm Śląski, Dąbrowa Górnicza Gołonóg, Dąbrowa Górnicza Sikorka, Dąbrowa Górnicza Wschodnia, Dąbrowa Górnicza Ząbkowice, Gliwice Łabędy, Imielin, Katowice Podlesie, Kobiór, Łaziska Górne, Łaziska Górne Brada, Mikołów Jamna, Mysłowice Brzęczkowice, Mysłowice Kosztowy, Nakło Śląskie, Nowy Bieruń, Przyszowice, Pyskowice, Rudziniec Gliwicki, Rzeczyce Śląskie, Sławków, Sosnowiec Dańdówka, Sosnowiec Kazimierz, Sosnowiec Porąbka, Taciszów, Tychy, Tychy Lodowisko, Tychy Żwaków
3	Będzin Miasto, Bytom, Chorzów Batory, Chorzów Miasto, Dąbrowa Górnicza, Dąbrowa Górnicza Strzemieszyce, Gliwice, Katowice Ligota, Katowice Piotrowice, Katowice Szopienice Południowe, Katowice Załęże, Mikołów, Mysłowice, Radzionków, Radzionków Rojca, Ruda Śląska, Sosnowiec, Sosnowiec Południowy, Świętochłowice, Tarnowskie Góry, Zabrze
4	Będzin, Bytom Karb, Bytom Północny, Chorzów Stary, Dąbrowa Górnicza Pogoria, Gliwice Kuźnica, Katowice Brynów, Katowice Zawodzie, Knurów, Mysłowice Brzezinka, Ruda Chebzie, Tychy Aleja Bielska, Tychy Grota Roweckiego, Tychy Zachodnie

Table 4

Numerical values of characteristics of land use for each class

Class	Characteristic of land use	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
1	average number	1079	179	105	37	24	88	27	0	693
	average density [1/km^2]	536.82	89.05	52.24	18.41	11.94	43.78	13.43	0.00	344.78
	percentage share [%]	43.34	8.02	4.70	1.66	1.08	3.94	1.21	0.00	31.05
2	average number	390.14	7.83	14.93	25.21	0.55	3.31	1.03	0.45	182.48
	average density [1/km^2]	194.10	3.89	7.43	12.54	0.27	1.65	0.51	0.22	90.79
	percentage share [%]	62.33	1.25	2.39	4.03	0.09	0.53	0.17	0.07	29.19
3	average number	650.29	46.38	79.67	82.10	5.33	15.52	12.14	1.57	289.30
	average density [1/km^2]	323.53	23.08	39.64	40.84	2.65	7.72	6.04	0.78	143.95
	percentage share [%]	55.00	3.92	6.74	6.94	0.45	1.31	1.03	0.13	24.47
4	average number	224.43	23.00	32.14	69.57	1.50	7.14	2.43	1.36	86.29
	average density [1/km^2]	111.66	11.44	15.99	34.61	0.75	3.55	1.21	0.68	42.93
	percentage share [%]	50.11	5.14	7.18	15.53	0.33	1.59	0.54	0.30	19.27

As presented in Table 4, class 1 contains the stations with the most objects of the built environment in their vicinity. Residential buildings constitute the majority of these; however, there are also significant numbers of office buildings, commercial and service buildings, and educational buildings. Thus, the mix of land use in the vicinity of stops or stations assigned to class 1 is high. In class 2, the most common objects of the built environment in the vicinity of railway stops or stations are residential buildings. This means that such stops and stations are mostly located in residential areas, with fewer objects of different functions. Passengers who use such stops and stations usually do so to travel to or from home. Classes 3 and 4 encompass stops and stations that are characterized by a similar land use mix. The only exception is the larger share of industrial buildings and warehouses in the case of stops and stations assigned to class 4. These two classes are differentiated by the total number of buildings – in class 3, the density of the built environment is significantly higher than in class 4.

The spatial distribution of stops and stations assigned to each class is presented in Fig. 5.

Based on Fig. 5, it can be stated that stops and stations assigned to classes 3 and 4 are usually located in relatively large cities (mostly in the core of the GZM). Moreover, class 3 stops and stations contain more significant stops and stations in each administrative unit. The density and mixture of built environment objects in the vicinity of such stops and stations are usually higher than in the case of class 4. Stops and stations assigned to class 2 are usually located outside of the core of the metropolis or in less densely built areas. The only station assigned to the first category, Katowice, is located at the center of the largest city in the metropolis.

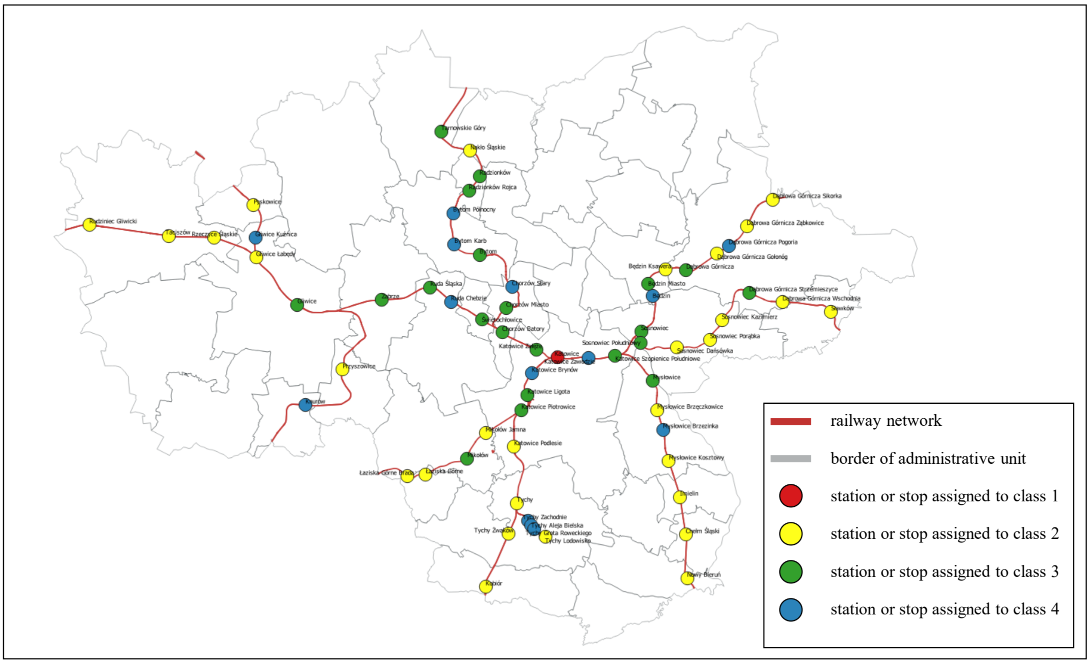

Fig. 5. Spatial distribution of railway stops and stations with division into classes

Fig. 6 presents examples of each class in terms of the land use structure in the vicinity of stops and stations.

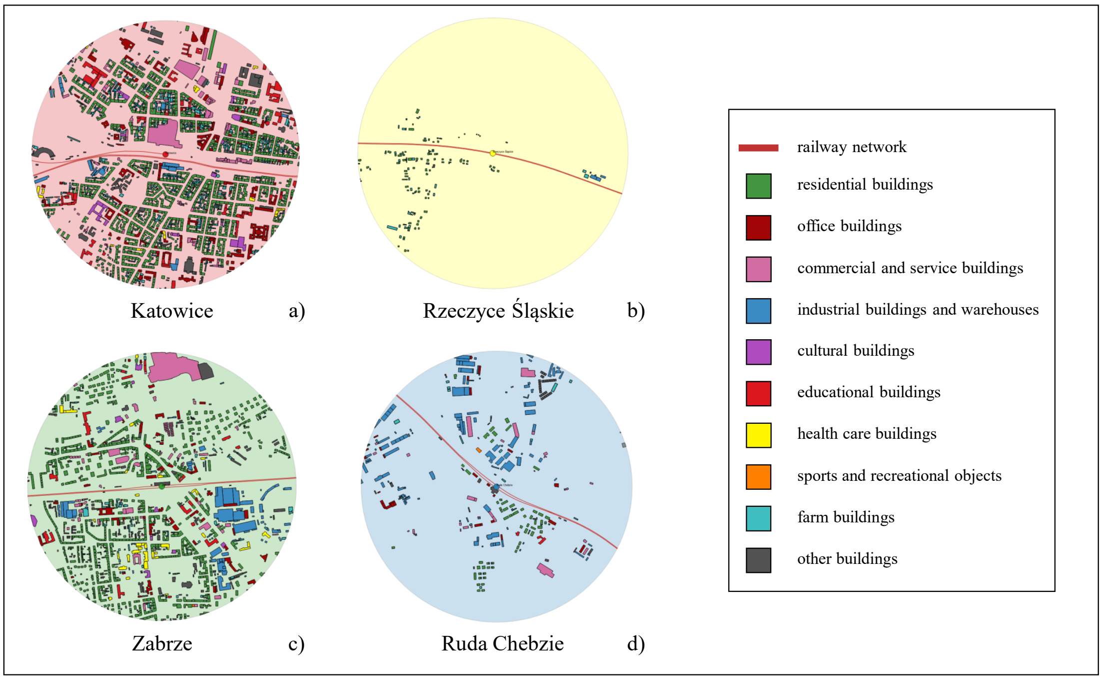

Fig. 6. Examples of land use in the vicinity of stops and stations in each class: a) class 1, b) class 2, c) class 3, d) class 4

Fig. 6 depicts visible differences in the density of land use for each class of stops and stations. The built environment of class 1 is the densest, whereas classes 2 and 4 have low-density built environments. Stops and stations assigned to classes 1 and 3 are usually located in the centers of administrative units. Therefore, the surrounding buildings are mostly residential buildings; however, the land use mixture is larger than in class 2.

5. CONCLUSIONS

In the presented analysis, it has been assumed that the density of the built environment influences the accessibility of railway stops and stations. Therefore, data on all buildings in the surroundings of all railway stops and stations in the area of analysis have been gathered to assess the accessibility of such objects. These data have been used to assign all analyzed stops and stations into appropriate classes based on the type of land use structure in their vicinity. Classes that have been obtained in this way are distinguished by the density and diversity of the built environment in the vicinity of each stop or station. The area of analysis was the GZM.

The Katowice station is characterized by the highest level of potential for transport demand in the study area. The density of the built environment and the mixture of land use in the vicinity of this station are the highest of all analyzed railway stops and stations. Stations assigned to class 3 are also characterized by high transport demand. Although the density of the built environment in their surroundings is lower than in the case of class 1, it is still high. The mix of land use in the third class is also high, suggesting that passengers may use these stations for trips with multiple purposes. Classes 2 and 4 are recognized by lower levels of density. However, the land use mix of class 4 is higher than that of class 2; specifically, there is a visible dominancy of residential and single-family buildings in the 800-m equidistant area around railway stops and stations assigned to class 4. Therefore, such stops and stations are most often used during trips to and from passengers' homes.

The classification of railway stops and stations in terms of the land use structure in their surroundings can be a preliminary step taken before assessing accessibility. Such classification enables the grouping of objects for further analysis within groups by considering a similar level of the built environment in the vicinity of the facility. Future studies should encompass different approaches to the role of land use in the analysis of accessibility (e.g., different types of built environment objects should be used for analyses). Doing this would allow assessments of potential transport demand and further the accessibility of railway stations and stops for specific trip purposes and groups of travelers. It is also of great importance to consider other characteristics of land use, in addition to the general type and function (e.g., the number of floors or the number of inhabitants) to ensure a comprehensive analysis. One potential limitation of the proposed method is the adoption of a simplified determination of Euclidean catchment areas; this kind of determination does not reflect the connectivity of the built environment components with the rail stops and stations. In further work, it is worth considering more advanced methods, in which the road and street network and its parameters are also considered.

References

1. Macioszek, E. Analysis of the volume of passengers and cargo in rail and road transport in Poland in 2009-2019. *Scientific Journal of Silesian University of Technology. Series Transport*. 2021. Vol. 113. P. 133-143. ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2021.113.10.
2. Kamiński, W. Comparison of selected railway lines in Poland using the Analytical Hierarchy Process method. *Scientific Journal of Silesian University of Technology. Series Transport*. 2020. Vol. 108. P. 73-84. ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2020.108.7.
3. Gołębiowski, P. & Jacyna, M. & Stańczak, A. The Assessment of Energy Efficiency versus Planning of Rail Freight Traffic: A Case Study on the Example of Poland. *Energies*. 2021. Vol. 14. 5629. DOI: https://doi.org/10.3390/en14185629.

4. Gołębiowski, P. & Żak, J. & Jacyna-Gołda, I. Approach to the Proecological Distribution of the Traffic Flow on the Transport Network from the Point of View of Carbon Dioxide. *Sustainability* 2020. Vol. 12. 6936. DOI: https://doi.org/10.3390/su12176936.
5. Liu, R. & Moini, N. Benchmarking transportation safety performance via shift-share approaches. *Journal of Transportation Safety & Security.* 2015. Vol. 7. No. 2. P. 127-137.
6. Szaciłło, L. & Jacyna, M. & Szczepański, E. & Izdebski, M. Risk assessment for rail freight transport operations. *Eksploatacja i Niezawodność – Maintenance and Reliability.* 2021. Vol. 23 No. 3. P. 476-488. DOI: http://doi.org/10.17531/ein.2021.3.8.
7. Gołębiowski, P. & Kukulski, J. Preliminary study of shaping the railway track geometry in terms of their maintenance costs and capacity. *Archives of Transport.* 2020. Vol. 53. No. 1. P. 115-128. DOI: https://doi.org/10.5604/01.3001.0014.1787.
8. Soczówka, P. & Żochowska, R. & Barchański, A. Nodes in the railway network as potential places of integration of public transport. *Nodes in transport networks – research, data analysis, and modelling.* 2020. P. 63-81.
9. Faron, A. Rapid agglomeration light rail system as a response to spatial planning in the Cracow Metropolitan Area: typology of train stops. *Scientific Journal of Silesian University of Technology. Series Transport*. 2016. Vol. 92. P. 41-51. ISSN: 0209-3324. DOI: 10.20858/sjsutst.2016.92.5.
10. Cieśla, M. & Sobota, A. & Jacyna, M. Multi-criteria decision making process in metropolitan transport means selection based on the sharing mobility idea. *Sustainability* 2020. Vol. 12(7231). DOI: https://doi.org/10.3390/su12177231.
11. Soczówka, P. & Kłos, M.J. & Żochowska, R. & Sobota, A. An analysis of the influence of travel time on access time in public transport. *Scientific Journal of Silesian University of Technology. Series Transport*. 2021. Vol. 111. P. 137-149. ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2021.111.12.
12. Gonzalez-Feliu, J. & Palacios-Argüello, L. & Suarez-Nuñez, C. Links between freight trip generation rates, accessibility and socio-demographic variables in urban zones. *Archives of Transport*. 2020. Vol. 53. No. 1. P. 7-20. DOI: https://doi.org/10.5604/01.3001.0014.1738.
13. Stępniak, M. & Pritchard, J.P. & Geurs, K.T. & Goliszek, S. The impact of temporal resolution on public transport accessibility measurement: Review and case study in Poland. *Journal of Transport Geography.* 2019. Vol. 75. P. 8-24.
14. Rosik, P. Motywacje podróży a dostępność potencjałowa gmin w Polsce. [In Polish: Travel motivations and potential accessibility of communes in Poland]. In: Rosik, P. & Wiśniewski, R. (Eds.). *Dostępność i mobilność w przestrzeni.* [In Polish: *Accessibility and mobility in space*]. Warsaw: PAN IGiPZ. 2012. P. 37-47.
15. Hansen, W.G. *Accessibility and residential growth*. 1959. Massachusetts Institute of Technology. 46 p.
16. Vickerman, R.W. Accessibility, attraction, and potential: a review of some concepts and their use in determining mobility. *Environment and Planning A*. 1974. Vol. 6. P. 675-691.
17. Szarata, A. Wpływ dostępności transportowej na liczbę podróży w obszarach miejskich. [In Polish: The impact of transport accessibility on the number of trips in urban areas]. In: Rosik, P. & Wiśniewski, R. (Eds.). *Dostępność i mobilność w przestrzeni.* [In Polish: *Accessibility and mobility in space*]. Warsaw: PAN IGiPZ. 2012. P. 157-165.
18. Bok, J. & Kwon, Y. Comparable measures of accessibility to public transport using the general transit feed specification. *Sustainability.* 2016. Vol. 8. No. 224. P. 1-13.
19. Papaioannou, D. & Martinez, L.M. The role of accessibility and connectivity in mode choice. A structural equation modeling approach. *Transportation Research Procedia*. 2015. Vol. 10. P. 831-839.
20. Sierpiński, G. Miary dostępności transportowej miast i regionów. [In Polish: Measures of transport accessibility of cities and regions]. *Scientific Journal of Silesian University of Technology. Series Transport*. 2010. Vol. 66. P.91-96.
21. Geurs, K.T. & van Eck, J.R. *Accessibility measures: review and applications.* 2001. Urban Research Centre. Utrecht University.

22. Geurs, K.T. & van Wee, B. Accessibility evaluation of land use and transport strategies: review and research directions. *Journal of Transport Geography*. 2004. Vol. 12. P. 127-140.
23. Albacete, X. & Olaru, D. & Paul, V. & Biermann, S. Measuring the accessibility of public transport: A critical comparison between methods in Helsinki. 2004. *Applied Spatial Analysis and Policy*. Vol. 10. No. 2. P. 1-28.
24. Rosik, P. *Multimodalna dostępność transportem publicznym gmin w Polsce*. [In Polish: *Multimodal accessibility by public transport of communes in Poland*]. Warsaw: IGiPZ PAN. 2017.
25. Monajem, S. & Nosratian, F.E. The evaluation of the spatial integration of station areas via the node place model; an application to subway station areas in Tehran. *Transportation Research Part D: Transport and Environment.* 2015. Vol. 40. P. 14-27. DOI: https://doi.org/10.1016/j.trd.2015.07.009.
26. Nigro, A. & Bertolini, L. & Moccia, F. D. Land use and public transport integration in small cities and towns: Assessment methodology and application. *Journal of Transport Geography.* 2019. Vol. 74. P. 110-124. DOI: https://doi.org/10.1016/j.jtrangeo.2018.11.004.
27. Soczówka, P. Method of classification of spatial units for transit-related analyses. *Transport Problems*. 2021 Vol. 16. No. 3. P. 17-28. DOI: 10.21307/tp-2021-038.
28. Reusser, D.E. & Loukopoulos, P. & Stauffacher, M. & Scholz, R. W. Classifying railway stations for sustainable transitions – balancing node and place functions. *Journal of Transport Geography.* 2008. Vol. 16. P. 191-202. DOI: https://doi.org/10.1016/j.jtrangeo.2007.05.004.
29. Zemp, S. & Stauffacher, M. & Lang, D.J. & Scholz, R.W. Classifying railway stations for strategic transport and land use planning: Context matters! *Journal of Transport Geography.* 2011. Vol. 19. No. 4. P. 670-679. DOI: https://doi.org/10.1016/j.jtrangeo.2010.08.008.
30. Eizaguirre-Iribar, A. & Grijalba, O. & Hernández-Minguillón, R.J. An Integrated Approach to Transportation and Land-Use Planning for the Analysis of Former Railway Nodes in Sustainable Transport Development: The Case of the Vasco-Navarro Railway. *Sustainability*. 2021. Vol. 13(322). DOI: https://doi.org/10.3390/su13010322.
31. Kamruzzaman, Md. & Baker, D. & Washington, S. & Turrell, G. Advance transit oriented development typology: case study in Brisbane, Australia. *Journal of Transport Geography.* 2014. Vol. 34. P. 54-70. DOI: https://doi.org/10.1016/j.jtrangeo.2013.11.002.
32. Zhang, Ce. & Sargent, I. & Pan, X. & Li, H. & Gardiner, A. & Hare, J. & Atkinson, P.M. An object-based convolutional neural network (OCNN) for urban land use classification. *Remote Sensing of Environment.* 2018. Vol. 216. P. 57-70. DOI: https://doi.org/10.1016/j.rse.2018.06.034.
33. Cascetta, E. *Transportation Systems Analysis. Springer*. New York. 2009. 742 p.
34. Ortuzar, J.D. & Willumsen, L.G. *Modelling Transport. 4th Edition*. Wiley. 2011. 607 p.
35. Karoń, G. *Kształtowanie ruchu w miejskich sieciach transportowych z wykorzystaniem inżynierii systemów*. [In Polish: *Shaping traffic in urban transport networks using systems engineering*]. Gliwice: Publishing House of the Silesian University of Technology. 2019. 364 p.
36. Everitt, B.S. & Landau, S. & Leese, M. & Stahl, D. *Cluster Analysis. 5th Edition.* Wiley. 2011. 346 P.
37. Prus B. & Król, K. Ocena zastosowania wybranych metod taksonomicznych do klasyfikacji zjawisk społeczno-gospodarczych. [In Polish: Assessment of the application of selected taxonomic methods for the classification of socio-economic phenomena]. *Acta Sci. Pol. Formatio Circumiectus.* 2017. Vol. 16. No. 2. P. 179-197.
38. Rusu, M. A typology of rural areas in Danube Region. *Procedia Economics and Finance.* 2015. Vol. 22. P. 733-741.
39. *Metropolis GZM Webpage.* Available at: https://metropoliagzm.pl.
40. *Bank of Local Data.* Available at: https://bdl.stat.gov.pl.

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