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MAKING BUS TRANSPORTATION MORE ACCESSIBLE: A RZESZÓW CASE STUDIE

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Abstract – Public transportation accessibility can be assessed in a variety of ways. The article presents some approaches to measuring the accessibility of public transportation in cities. The simplest method involves analysing the accessibility of public transportation stops, considering the distance from potential users. Other approaches suggest additionally incorporating information on the number of lines or services serving specific stops. However, these methods often lack the granularity needed for comprehensive planning. The paper proposes an alternative approach that utilizes Intelligent Transportation Systems (ITS) infrastructure and Big Data to evaluate public transportation accessibility and utilization within a city. In this paper, accessibility is assessed using a usage-based, zone-level diagnostic approach enabled by continuous APC/ITS data; pedestrian access constraints to individual stops are left for a subsequent, location-specific step. The 4-week dataset is used to demonstrate the proposed workflow for analysing continuous APC data. The approach is directly scalable to full-year datasets to examine seasonality. These data, which recorded passenger entries, were combined with statistical information on the number of residents and workplaces in different urban areas. The integration of these sources enabled a comprehensive evaluation of public transport accessibility. A significant correlation was found between transit usage and both population and jobs in each area, with a stronger relationship for population. This methodology allows visualization of transit usage citywide and helps identify low ridership areas. These findings can inform transit planning by highlighting mismatches between service usage and local demand.

Key words – mobility management, public transportation accessibility, transport data analysis.

JEL Classification – R41, R42, R58

INTRODUCTION

In developing countries, and particularly in European Union countries, there is a strong emphasis on efficient public transportation, which is intended to alleviate traffic congestion and reduce harmful environmental emissions [1-2]. Efficient transportation requires the implementation of appropriate strategies aimed at improving punctuality, attractiveness, and user satisfaction, as well as introducing traffic priorities for public transport vehicles [3-4], updating and monitoring schedules tailored to residents' needs [5-6]. The selection of appropriate actions is the result of a previously conducted diagnosis, carried out for the purpose of implementing strategic documents such as the Sustainable Urban Mobility Plan (SUMP) [7-8].

This study delves into the case of Rzeszów, Poland, to explore how bus network accessibility can be analyzed and optimized. Various methodologies employed in recent studies are examined, encompassing diverse aspects of accessibility. These methodologies are then applied to analyze the existing bus network service in Rzeszów. The chapter begins by reviewing relevant literature focused on different approaches to analyzing bus network accessibility. Studies that utilize various data sources, including geospatial data, field surveys, and GPS data, are explored to assess travel behaviour, accessibility levels, and service quality. Next, the specific case of Rzeszów is delved into. Rzeszów offers a valuable case study due to its well-developed Intelligent Transportation System (ITS) that provides a wealth of data for analysis. The data sources used in this study are described. Following the data description, the analysis findings are presented. Section 4 focuses on the diagnosis of the existing bus network service across different urban areas. A map illustrating disparities in passenger ridership across the city is presented. Section 5 delves deeper into the relationship between bus ridership and population density and workplaces. Indicators are introduced that define the impact of the number of bus users per resident and per workplace for individual zones. The relationship between these factors and bus ridership is then analyzed using Pearson's linear correlation (Section 5.1). This analysis paves the way for further investigation into areas with low ridership or discrepancies between expected and observed usage patterns.

1. LITERATURE REVIEW AND RESEARCH METHODS

Public transportation accessibility is a cornerstone of sustainable urban development. This chapter delves into existing research to understand how accessibility is analyzed and optimized for bus networks. To enhance public transportation accessibility in urban areas, several best practices can be implemented. Firstly, a comprehensive measurement model should be developed to assess the adequacy of public transport services in residential areas, considering factors like population density and geographical locations [9-10]. Secondly, utilizing spatial and temporal analysis methods can help in evaluating the current level of accessibility and potential demand for public transport services, enabling targeted improvements where needed [11]. Additionally, integrating multi-modal transportation data can aid in understanding accessibility patterns and identifying areas for enhancement [12-13]. In article [14], an example of conducted analyses of the functioning of the transport system in Bielsko-Biała for the purpose of implementing a Sustainable Urban Mobility Plan (SUMP) is presented. Various data sources such as geospatial data and field surveys were utilized to accomplish the task. One of the effects of the conducted work was understanding commuting behaviours. Based on this, it was established that travels within the city are usually carried out using a single mode of transport (mainly by private car 67.1% or by bus 25.6%). Problems with coordinating the city railway system with buses were diagnosed. Through the accessibility analyses conducted in a GIS environment, it was indicated that integrating two modes of transportation (city railway and city bus) could increase accessibility to major points of public utility (POI) by up to 72%. The accessibility of bus transportation is also important for social reasons. An interesting approach to studying the accessibility of bus transport was presented using the example of the Wrocław agglomeration [15]. The study focused on analyzing the accessibility of bus transport in the municipalities adjacent to Wrocław. As the authors emphasize, ensuring the same level of transportation service throughout the entire agglomeration is impossible, resulting in areas of very low-quality public transport service and areas of very good quality where both bus and rail transport are available. For this purpose, a numerical analysis was conducted based on the empirical Bayesian Kriging method to determine areas with different levels of accessibility to bus transport. This way, directions for the development of bus transport in the agglomeration were identified, which were tested using macro-simulation models executed in the PTV Visum environment. In Article [16], the objective was to investigate the factors that encourage Bus Rapid Transit (BRT) users in Yogyakarta to use bicycles as feeder transport and to determine their preferences for cycling facilities. Data were collected through a questionnaire distributed to 200 randomly selected BRT users over 30 days. The data was then analyzed using multiple regression analysis. Understanding BRT user preferences is crucial for planning and implementing effective public transportation services. This study suggests that there is potential to increase bicycle use as feeder transport for BRT users in Yogyakarta. Improving cycling infrastructure and promoting multimodal transportation can contribute to reducing car dependency and improving the sustainability of public transportation in the city questionnaire was distributed to 200 randomly selected BRT users.

Bus transport availability can be assessed through various methods, including using GPS data to measure reliability, accessibility, and availability [17]. This paper introduces an approach to measure the quality of service (QoS) of public city bus transportation in Bangkok using GPS data analytics. QoS scores were calculated for bus routes, considering factors like reliability, accessibility, and availability. The analysis revealed that while most routes functioned well with high scores, some areas showed room for improvement. Furthermore, evaluating bus stop accessibility is crucial for promoting sustainable mobility. This can be achieved by considering both objective features (like infrastructure) and passenger preferences to determine overall accessibility levels. The paper [18] identifies typical activity-travel patterns within the population. These results offer a comprehensive assessment of how well public transportation meets the needs of different groups and areas. This highlights the importance of tailoring approaches to address the varying demand patterns. The article [19] addresses the issue of spatial planning of residential areas in the context of transportation services. Using GIS, simulation, and optimization tools, the study focuses on analyzing the impact of changes in bus line frequencies on service levels and horizontal equity in Palma, Spain. Different types of spatial planning are compared to determine the optimal bus line frequencies for sustainable service. The article recommends combining zones of different sizes to improve the quality of transportation services, warning against misdiagnosing needs when using large spatial units.

2. DATA SOURCES IN TRANSPORT ANALYSIS

Making a proper diagnosis in transportation analyses requires taking a "snapshot" that illustrates the current state of the bus system. Typically, field studies are conducted to gather crucial information for this purpose. Nowadays, many modern cities are developing Intelligent Transportation Systems (ITS), which automatically collect a large amount of data. Rzeszów is one of the cities that has strongly supported the development of ITS systems for many years. Thanks to this, the collected data can be used in operational analyses, optimizing, for example, schedules, as well as in strategic analyses, enabling the shaping of development strategies. For the purposes of the article, BIG DATA provided by the Public Transport Authority were utilized. Data collected by onboard computers installed in over 95% of all buses operating daily in the city enable the collection of trip reports containing information such as:

- bus fleet number,
- line number,
- direction description,
- stop name,
- actual arrival time at the stop,
- deviation from the planned arrival time,
- dwell time at the stop,
- passenger flows,
- bus stop boarding and alighting data.

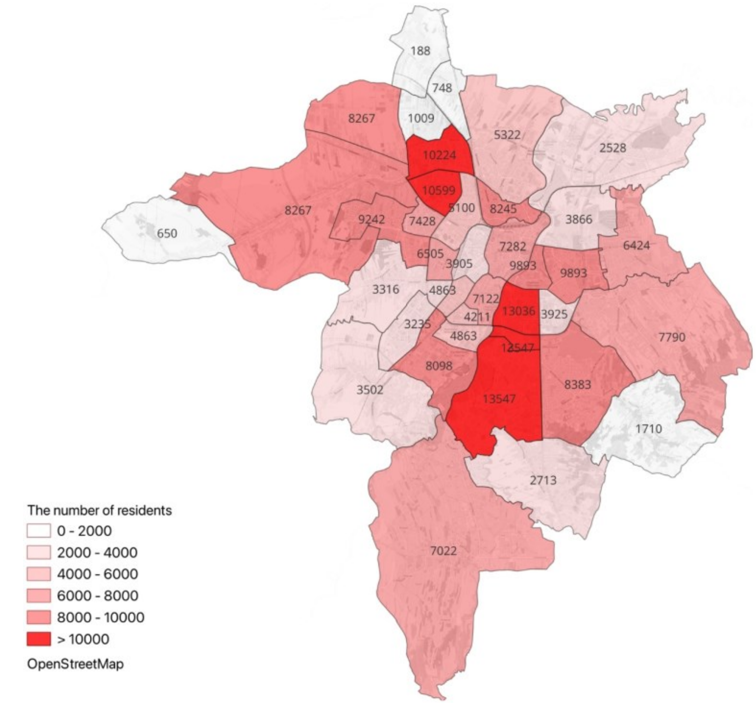

Fig. 1. Resident density across transportation zones

The collected data allows for a comprehensive analysis of how individual bus lines and bus stops function within Rzeszów's urban bus transportation system. The selected 4-week period serves as a baseline example, the objective is to present a replicable processing pipeline for large-scale APC data, not to claim full seasonal representativeness from this single window.

This system comprises 60 bus lines, with 44 operating solely within the city and 16 connecting Rzeszów to neighbouring municipalities. The number of lines serving areas of the city varies from 1 to 33 bus lines per section. The city center has the highest number of sections with several bus lines operating. On average, over 110,000 people use bus transportation during a typical working day.

Additionally, current geospatial data containing information about the number of residents, the estimated number of jobs, the transportation network, and the bus stop locations were obtained from the municipal urban planning office. In this way, the city was divided into 38 transportation zones for which detailed analyses of bus system utilization will be conducted in subsequent stages.

Each area was assigned parameters indicating the number of residents and the number of workplaces. In Figure 1, which shows the population density, densely built-up areas, including those with multi-family housing where the population is high, are marked in darker colours, while areas with a smaller population are marked in lighter colours. The largest number of residents is found in areas located in the central part of the city and exceeds 10,000 people.

The number of jobs is presented in Figure 2. Similarly to the number of residents, areas with the highest number of workplaces are marked in darker colours, while areas with a smaller number of jobs are marked in lighter colours. In this way, the city center and industrial service districts located north and south of the city center stand out clearly against the background of the map.

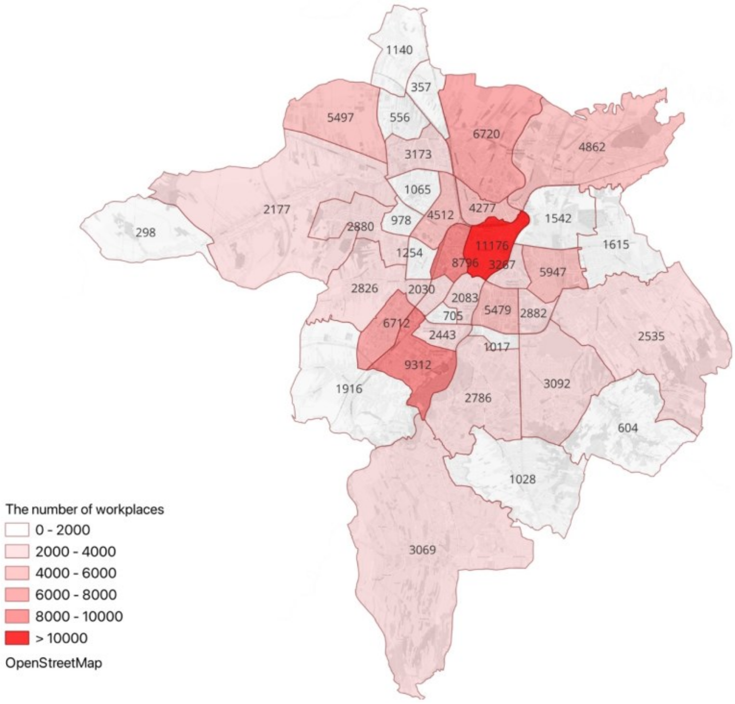

Fig. 2. Workplaces across city districts

3. DIAGNOSIS OF THE EXISTING BUS NETWORK SERVICE IN A PARTICULAR DISTRICT

With over 800 bus stops, Rzeszów boasts a comprehensive bus network. Thanks to access to a large database containing full information about the number of passengers boarding and alighting at individual stops, it was possible to conduct an analysis of bus ridership across different urban areas. Based on this, a map was developed illustrating the number of passengers boarding at stops located within designated transportation zones. The results show significant disparities in the number of passengers in different areas, which in extreme cases can reach several thousand individuals. A certain trend can be discerned in the illustration. The highest number of passengers is found in the central areas of the city, where nearly 20,000 people are recorded per day. A significantly lower number of passengers is observed in areas located at the city's border. Graphical representation of the results (Fig.3.) provides a big advantage, enabling the identification of areas that deviate from the trend. The lowest value was recorded in transportation zones in the northwest part of the city (29 passengers), which may be surprising as it is an area designated for the development of industrial zones, which are rapidly being developed.

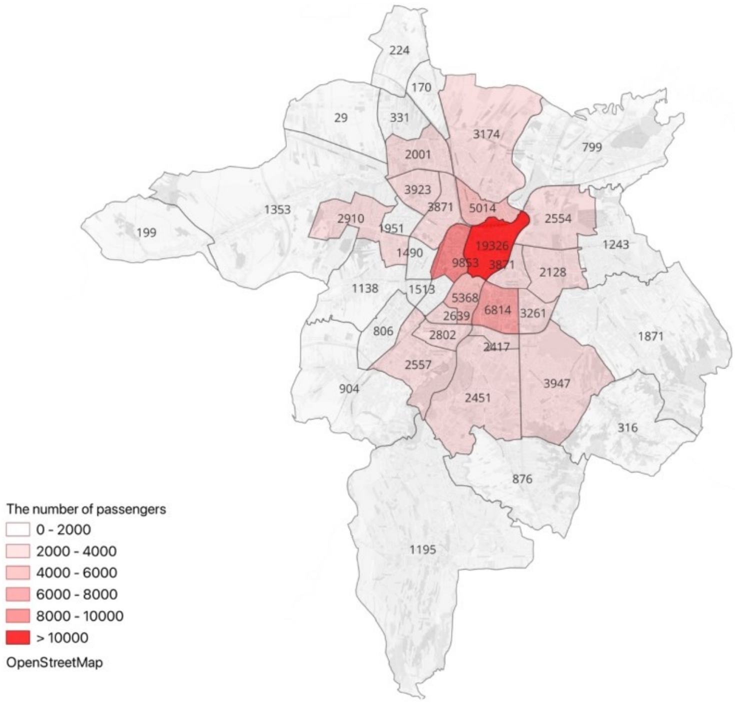

Fig. 3. The number of passengers across city districts

4. CALCULATING RESIDENT AND WORKPLACE RATIO IN CITY DISTRICT

The comparisons conducted in the previous steps have made it possible to develop indicators that define the impact of the number of bus transport users per resident or workplace for individual zones. Data were analyzed as passenger boardings (entries) recorded at stops. Each record included at least a stop identifier and timestamp and was aggregated to daily totals. Days or stop-day combinations with incomplete or clearly erroneous records (e.g., missing periods, implausible spikes) were excluded according to standard data quality rules used by the operator. Stops were assigned to transport zones using their geographic coordinates (a point-in-polygon operation). To compute boardings at the zone level, let $b_{s,t}$ denote the number of boardings at stop s in day t. The zone-level daily boardings are then calculated as:

$$P_{i,t}=\sum_{s\in i} b_{s,t} \tag{1}$$

where $s \in i$ denotes stops located in zone i.

A representative value for the analysed period T (four weeks) is computed as:

$$P_i = \frac{1}{\lceil T \rceil} * \sum\nolimits_{s \in T} P_{i,t} \tag{2}$$

Population R_i and the number of workplaces J_i were available for each zone i. Two dimensionless indicators were defined as:

$$I_{pop,i} = \frac{P_i}{R_i}$$
$$I_{job,i} = \frac{P_i}{J_i} \tag{3}$$

Both indicators are expressed as non-dimensional ratios. They can be interpreted as the average number of boardings per resident (or per workplace) in the analyzed period, for the chosen temporal aggregation.

The results presented in Figure 4 show that zones with darker colours exhibit high usage of public transportation, while zones with lighter colours have a small number of passengers relative to the number of residents. Almost 37% of transportation zones have the lowest bus transportation utilization rate, ranging from 0 to 25%. These zones are located both at the city's periphery and in its central part. These are areas that undoubtedly deserve scrutiny, especially the white spots in the central parts of the city. Particularly surprising is the low-rate ratio zone marked with a green border, near the center, dominated by multi-family housing and having a large population. Similar situations occur in zones marked blue border, where the number of bus lines operating in this area is 12. A utilization rate above 50% was achieved only in 31% of all transportation zones. Values exceeding 100% were recorded in the central part of the city, where the downtown area is located.

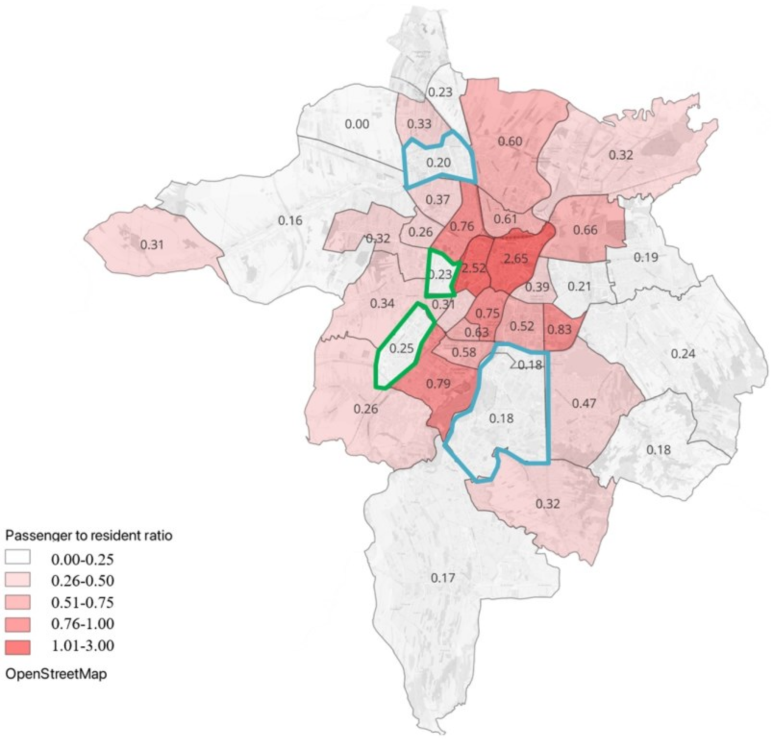

Fig. 4. Public transport usage per capita

In the next step, passenger numbers were compared with the number of workplaces (Fig. 5). In this case, over half of the areas achieved a high utilization rate of bus transportation exceeding 75%. Such a result is largely influenced by the often-low density of workplaces, for example, in areas where multi-family housing predominates, generating a large number of trips. As a result, this comparison yields a high frequency of elevated indicator values, which are associated with the number of trips generated not by workplaces but by residential development. However, it is worth examining areas where commercial and industrial development predominates and the number of residents is small. Such areas may include the industrial zone marked with a blue border, where the number of workplaces is almost twice as high as the number of residents. In predominantly residential zones with a small number of workplaces, the passenger-to-workplace ratio may be inflated due to a small-denominator effect and should therefore not be interpreted as employment-generated demand. In such cases, high values primarily reflect trips generated by residents rather than by employees. Consequently, this indicator is most informative when applied to employment-dominated or mixed-use zones, where it can reveal mismatches between observed ridership and the intensity of workplace activity.

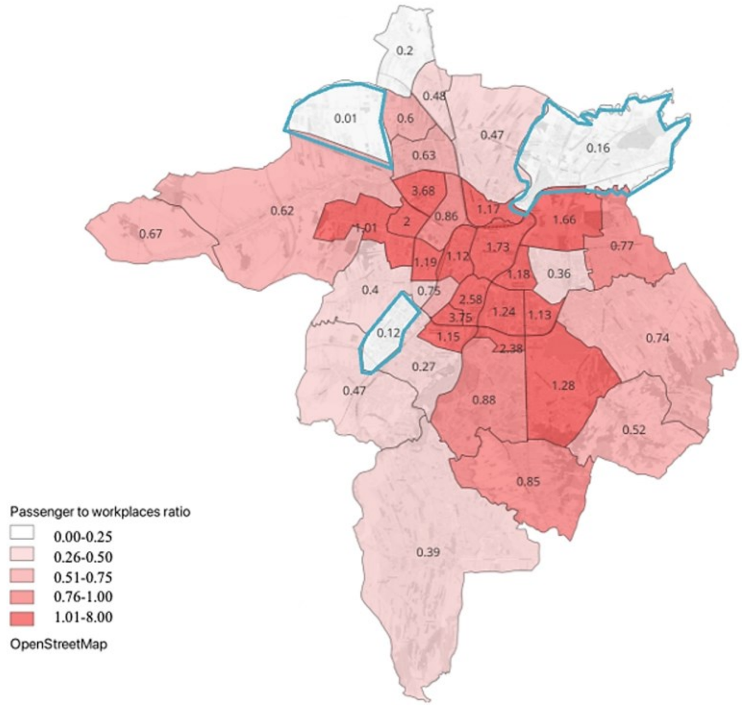

Fig. 5. Passenger to workplaces ratio by city district

4.1. Correlation Analysis of Passenger Ridership

The obtained indicators were subjected to statistical evaluation, the aim of which was to assess the correlation between the data groups compared to build the indicator. Pearson's linear correlation was used for the evaluation, in which the dataset of the number of residents was compared to the number of passengers and the number of jobs to the number of passengers. To quantify linear associations between zone-level variables, Pearson's correlation coefficient r was computed across number of zones. The statistical significance of the Pearson correlation coefficient was assessed using the standard Student's t-test for the null hypothesis of zero correlation $H_0{:}\rho = 0$. The test statistic was computed from r and the sample size n, and evaluated against a t-distribution with (n-2) degrees of freedom. Two-sided p-values were reported. This analysis helped determine the strength and direction of the relationship between these factors and bus ridership (Tab.1).

Table 1. Relationship between analyzed factors and bus ridership

Data sets	Pearson correlation coefficient	P-value
Number of passengers per resident	0.46	0.0037
Number of passengers per workplaces	0.39	0.0171

In both cases, a statistically significant correlation was obtained between the two variables. The correlation with workplaces should be interpreted as an aggregate association at the zone level. Passenger-to-workplace ratios may be inflated in zones with very low job counts. Furthermore, the correlation in both cases is positive, indicating that an increase in one variable should be expected to result in an increase in the other variable. The correlation results suggest that both the number of residents and the number of workplaces, although the correlation for the latter is slightly weaker in the given area, positively influence the number of passengers using public transportation. The more people live and work in a given area, the greater the demand for public transportation. On the other hand, the obtained correlation coefficient values indicate that there are areas within the analyzed area where no correlation exists. These are areas, for example, with a large number of residents and a small number of trips, represented as white spots on the map showing passenger-to-resident ratio indicators.

5. Discussion

This study helps to better understand public transport accessibility by using maps and large amounts of data from smart transport systems. Previous studies have demonstrated that accessibility can be assessed through a wide range of approaches from GIS-based spatial analyses to empirical examinations of travel behaviour and multimodal integration. These works underline that spatial planning strongly affects transport service quality, highlighting the need for locally adapted solutions that address diverse demand patterns.

As expected, the highest demand for public transport occurs in the city center. Moving away from the central areas toward the periphery, the demand gradually decreases. However, the ratio-based indicators applied in this study relating the number of passengers to the number of residents and workplaces provide a more detailed picture of transport dynamics, allowing for the identification of several zones with high population density but low levels of public transport usage. This finding indicates a possible mismatch between the supply of transport services and actual travel demand. Moreover, some industrial or mixed-use areas exhibited unexpectedly high passenger-to-job ratios, which may suggest that these zones generate trips not only related to commuting but also associated with other travel purposes.

The application of ITS and big data allows for more objective and granular insights into public transport performance than traditional surveys or manual counts. The results confirm a positive correlation between the number of residents and workplaces and bus ridership, supporting the assumption that areas with higher population or employment densities generate greater demand for public transport.

This study does not model pedestrian access to stops (e.g., barriers, crossings, or signal delays). Therefore, the presented indicators should be interpreted as a city-wide screening tool. For the shortlisted zones ("white spots"), a second-step analysis can refine results using pedestrian network-based walking times and barrier-aware catchment areas. The indicators are computed at the daily, zone-aggregated level and therefore do not distinguish between AM and PM peaks or between travel directions. This design choice reflects the screening purpose of the method: to identify zones with potential accessibility or service provision issues using stable, comparable metrics. Peak-period and direction-specific analyses can be conducted in a second step by segmenting APC records by time-of-day and by route direction, which is straightforward with continuous APC data.

From a methodological perspective, the study shows that relying solely on absolute passenger counts can lead to misinterpretation of accessibility patterns. Ratio-based indicators provide a more equitable assessment of service efficiency and highlight "white spots" of low usage that may require intervention. Future research could extend this analysis by integrating socio-economic variables, temporal dynamics, and travel attitudes, offering a more comprehensive understanding of accessibility and supporting the design of targeted, inclusive transport policies. Seasonal variation is not analysed in this paper because only one continuous baseline window is used. Future work will replicate the workflow for a full-year dataset.

CONCLUSIONS

The analysis of bus network accessibility in Rzeszów, Poland, demonstrates the value of data-driven approaches for improving the sustainability and efficiency of urban transport systems. By leveraging ITS-derived ridership data and geospatial aggregation, the study quantified public transport utilization in relation to residential and employment densities and highlighted zones requiring further investigation.

Quantitatively, strong spatial disparities were observed across the 38 transportation zones. Daily ridership ranged from 29 boardings at the city edge to nearly 20,000 boardings in central zones. After normalizing ridership by population, 37% of zones fell into the lowest utilization class (0–25%), while values above 50% occurred in 31% of zones, with ratios exceeding 100% in the downtown area. Pearson correlation confirmed statistically significant positive associations between boardings and both population and jobs, with a stronger relationship for population ($r = 0.46$, $p = 0.0037$) than for workplaces ($r = 0.39$, $p = 0.0171$). Importantly, several "white-spot" zones showed lower-than-expected usage relative to their demographic or service context, suggesting local mismatches between supply and realized demand.

From a planning perspective, the ratio-based indicators provide a more diagnostic view than raw passenger counts and support a balanced prioritization of interventions aimed at improving accessibility and equity. The proposed workflow offers a practical screening tool for identifying candidate areas for second-step analyses (e.g., barrier-aware pedestrian access, time-of-day patterns, and service design adjustments). More broadly, the framework can be transferred to other medium-sized cities seeking to implement demand-responsive and socially inclusive public transport strategies.

Efficient and accessible public transport remains essential for reducing congestion and environmental impacts in cities. The results of this study emphasize the importance of integrating spatial, demographic, and operational data into urban mobility planning. The methodological framework proposed here can serve as a reference for other medium-sized cities seeking to implement data-informed strategies that foster sustainable, inclusive, and demand-responsive public transport systems.

JAK UCZYNIĆ TRANSPORT AUTOBUSOWY BARDZIEJ DOSTĘPNYM : STUDIUM PRZYPADKU RZESZOWA

Artykuł przedstawia wybrane metody oceny dostępności transportu publicznego w obszarach miejskich. Zaproponowano w nim alternatywne podejście wykorzystujące infrastrukturę Inteligentnych Systemów Transportowych (ITS) oraz zasoby Big Data do analizy dostępności i wykorzystania transportu zbiorowego. W proponowanej metodzie dostępność oceniana jest poprzez diagnostykę opartą na rzeczywistym wykorzystaniu systemu transportowego na poziomie stref miejskich, bazującą na ciągłych danych pozyskiwanych z systemów ITS. Zastosowane podejście charakteryzuje się wysoką skalowalnością, umożliwiając analizę wieloletnich i sezonowych zmian popytu na transport publiczny. Dane dotyczące rejestrowanych wejść pasażerów zostały zintegrowane z informacjami statystycznymi opisującymi liczbę mieszkańców oraz miejsc pracy w poszczególnych obszarach miasta. Połączenie tych źródeł danych pozwoliło na przeprowadzenie kompleksowej oceny dostępności transportu publicznego. Wyniki analiz wykazały istotną zależność pomiędzy poziomem wykorzystania transportu zbiorowego, a liczbą mieszkańców i miejsc pracy, przy czym silniejszą korelację zaobserwowano w odniesieniu do liczby ludności. Opracowana metodyka umożliwia przestrzenną wizualizację wykorzystania transportu publicznego w skali całego miasta oraz identyfikację obszarów charakteryzujących się niskim poziomem wykorzystania usług przewozowych. Uzyskane wyniki mogą stanowić wsparcie dla procesów planowania transportu, pozwalając na identyfikację niedopasowań pomiędzy podażą usług transport-owych a lokalnym popytem.

Słowa kluczowe: zarządzanie mobilnością, dostępność transportu publicznego, analiza danych transportowych.

AUTHOR CONTRIBUTIONS

– conceptualization, M.Sz. (Mateusz Szarata) and I.T. (Igor Taran);
– methodology, M.Sz.;
– software, M.Sz.;
– validation, M.Sz. and I.T.;
– formal analysis, M.Sz.;
– investigation, M.Sz. and I.T.;
– writing - original draft preparation, M.Sz. and I.T.;
– writing -review and editing, M.Sz. and I.T.;
– visualization, M.Sz.;
– supervision, M.Sz. and I.T.;
– project administration, M.Sz.

All authors have read and agreed to the published version of the manuscript

Conflicts of Interest: The authors declare no conflicts of interest.

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