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Assessment of the Transport Accessibility of the City's Bicycle Rental System in Szczecin - GIS-Based Analysis

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Abstract:

Purpose: *The purpose of the paper is to identify areas in Szczecin (Poland) of strong accessibility and gaps in the bike-sharing system, focusing on the left bank of the city, where the city center is located. The study evaluates the distribution of bike stations in relation to walking distances and times, using buffer and drive-time analyses. By highlighting disparities in station locations and proposing recommendations for optimizing station placement, the paper seeks to improve the system's overall connectivity.*
Design/Methodology/Approach: *The development of accessibility analysis in this paper was prepared in ArcGIS Software, in particular ArcGIS Pro and ArcGIS Online. The Feature Analysis, including Use Proximity tool and in detail: Creation of buffers (ArcGIS Pro desktop version) and Creation of Drive-Time Areas (ArcGIS Online) was used. Preparation of the analysis is based on four steps: (1) preparation of the list of Bike-S stations in Szczecin, (2) obtaining geographic coordinates for each station, (3) creation of a map with a layer presenting the Bike-S system, (4) usage of ArcGIS Proximity Tools to gather information about buffers and drive-time areas for the analysed stations.*
Findings: *The findings reveal that the Bike-S system in Szczecin offers strong coverage in the city center, with most stations spaced approximately 300 meters apart, meeting public transport accessibility standards. However, gaps in accessibility exist, particularly in the westernmost and northern areas of the left bank, with notable disconnection near stations like "Kwiatowa" and "Rondo Uniwersyteckie-Kampus US." Buffer and drive-time analyses show that while most areas within a 1000-meter walking distance or 12-minute walking time are well-connected, peripheral areas face accessibility challenges. It highlights the equitable distribution of stations as a critical factor in achieving a more balanced and inclusive bike-sharing network. Overall, the study demonstrates the system's success in enhancing micro-mobility while identifying opportunities for optimization to better serve all areas of the city.*
Practical Implications: *This research made it possible to assess the transport accessibility of bike-rental scheme in the city of Szczecin. This type of analysis is useful from the point of view of city planners and public transport system operators. This type of research might be conducted in the other fields of public transport, including transport accessibility based on public transport stops, identification of a gaps in the whole system etc.*

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Originality/Value: *The interdisciplinary nature of the research allows for analysis from a broader perspective, looking at the transport problems of modern cities, in this case- city of Szczecin, and the tools that might be used to solve them- GIS software. The ex-post analysis proved the right direction of development of bike-sharing scheme in the city. The GIS tools that were used also proved that the spatial tools and analyses can improve planning and help to implement sustainable solutions in the city.*

Keywords: *Transport accessibility, bike rental system, bike-sharing, transport system, GIS.*

JEL codes: *O18, R40, R41, R42.*

Paper type: *Research article.*

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1. Introduction

Many cities increasingly prioritize sustainable transportation, understanding the effectiveness of bike-sharing systems that complements the whole network. Sustainable urban mobility is an imperative concern in modern cities, that shape their road to sustainable development in many areas, including transport. Shared micromobility systems, such as bike and scooter sharing are recognized as one of the most important contributors to sustainable behaviours in the cities, both complementing and enhancing public transport services (Hassam *et al.*, 2024).

Szczecin, a city in the northwest Poland, has made significant investments in developing its bicycle rental system as a means of improving transport accessibility and promoting alternative modes of transportation. Accessibility itself, especially in the case of urban transportation systems is a critical factor in promoting sustainable mobility and enhancing the quality of life for city residents.

This research paper aims to assess the transport accessibility of Szczecin's bicycle rental system (also called bike-sharing system)- Bike-S, providing information in relation to assessment of micro-mobility services on the urban area. It examines the spatial distribution of Bike-S stations and their coverage within Szczecin. The analysis utilizes ArcGIS software to determine bike-service areas and identify potential gaps in coverage. This paper covers the area of transport economics and

management research also including geospatial analysis. Its interdisciplinary nature allows for analysis from a broader perspective, looking at the transport problems of modern cities, in this case- city of Szczecin, and the tools that might be used to solve them GIS software.

2. Literature Review

2.1 Transport Accessibility

Accessibility is a fundamental concept in transportation and urban planning, as it measures the "ease" with which people can overcome spatial obstacles and reach essential services and facilities (Lei *et al.*, 2019).

However, the term "transport accessibility" often carries different meanings across scientific disciplines, reflecting its multifaceted nature. In urban planning, accessibility emphasizes connectivity to jobs, healthcare, and services (Coppola *et al.*, 2020), and also acts as a prerequisite for the modal shift paradigm, which encourages transitioning from car dependency to more sustainable modes of transport such as public transit, cycling, and walking (Kowalska, 2024).

Conversely, in social sciences, it may encompasses issues of equity, emphasizing disparities in access due to socioeconomic or demographic factors (Litman, 2024; Stacy *et al.*, 2020). In economics, accessibility is linked to productivity and regional growth, as improved transport networks drive economic activity and urbanization. These varied interpretations underscore the term's adaptability and the broad impacts of transport systems on societal structures and individual well-being (Kwarciński, 2017).

Given its interdisciplinary relevance, the study of transport accessibility has expanded to explore distinct types that address these diverse meanings. These include spatial accessibility, which evaluates physical proximity to transport networks and destinations, and temporal accessibility, focusing on travel times and service frequency (Coppola *et al.*, 2020).

Another critical type is economic accessibility, which examines the affordability of transport services for different population groups. Additionally, digital accessibility has emerged in modern contexts, reflecting how online platforms and smart technologies enhance mobility planning. The emphasis on a specific type of accessibility often depends on the discipline's focus: urban planners may prioritize spatial and temporal accessibility to improve efficiency, while social scientists tend to examine economic accessibility to address equity concerns (Litman, 2024).

To bridge these dimensions, the concept of transport accessibility serves as a unifying framework to assess how well transportation systems meet the diverse needs of urban populations. By integrating these perspectives, research on

accessibility moves beyond singular metrics to capture multifaceted impacts on mobility and urban dynamics. This holistic view becomes particularly relevant when applied to specific transport modes, such as cycling, where interactions between spatial, temporal, economic, and digital factors uniquely shape accessibility outcomes.

Recognizing these interdependencies provides a basis for systematic reviews that investigate the complex determinants of accessibility in varied transport contexts (Pourramazani and Miralles-Garcia, 2023; Valentini *et al.*, 2023).

A literature review on transport accessibility within the context of bicycle transport has been carried out using the Scoping Literature Review method, an approach well-suited for exploring topics with broad scope and diversity. This method allows to identify the key research areas, inter alia infrastructural, social, economic or technological, which may influence the transport accessibility of urban cycling.

Scoping Review enables the collection of a broad body of literature, including qualitative, quantitative and theoretical studies, which allows for a comprehensive understanding of the issue (Peters *et al.*, 2020; Munn *et al.*, 2018). The process was divided into three stages: literature review and selection, data extraction and mapping, and analysis of the mapped content.

Firstly, keywords were identified, to investigate literature related to transport accessibility in the context of bicycle transport. A query was created for the keywords ‘accessibility’ and ‘bicycle’ in the Web of Science database, which is one of the most reputable and reliable international scientific databases of journal publications.

A single article database was used, as this allowed methodological consistency in the article search, selection and analysis process. The following formula was used to identify relevant publications: ((TI=(‘accessibility’ and ‘bicycle’)) OR AK=(‘accessibility’ and ‘bicycle’)) OR AB=(‘accessibility’ and ‘bicycle’)).

This query yielded 324 publications. After narrowing the scope to English- and Polish-language literature, eliminating research fields irrelevant to the study's focus, and excluding publications not pertinent to the research, the final dataset comprises 71 publications.

The next stage involved mapping and structuring the selected literature. The Scoping Literature Review employed the VOSviewer tool to map and visualise the links between concepts in the scientific literature. VOSviewer is based on a "visualization of similarities" technique, designed to analyze and visualize network data, such as bibliometric networks, and enables the creation of maps that display the relationships between different keywords or concepts.

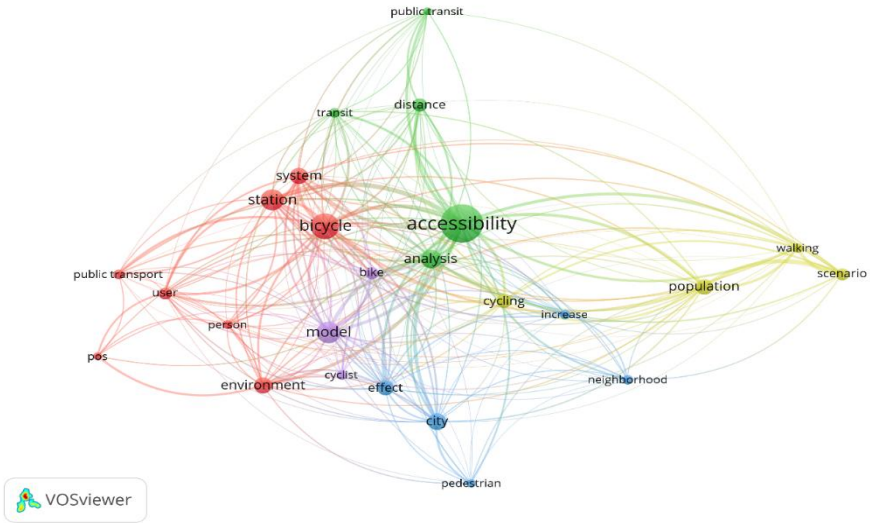
The tool identifies the most frequently occurring terms in the analysed literature, groups them according to their interrelationships and distinguishes the main themes and research areas (Van Eck and Waltman, 2019; Van Eck and Waltman, 2017). Using VOSviewer, a co-occurrence analysis of keywords was carried out to visually show the main research areas and their interconnections, focusing on topics related to urban bicycle transport accessibility.

Keywords are important in the literature mapping process as they reflect relevant issues and research directions, enabling a better understanding of the structure and development of a field (Mańkowska and Pettersen-Sobczyk, 2024).

Literature mapping using VosViewer was carried out on the basis of the selected 71 publications. The minimum number of occurences was set default on 10, therefore of the 1788 terms, 32 met the threshold. Subsequently, the most relevant terms were selected, in effect, 25 items remained.

Figure 1 shows the results of the co-occurrence analysis conducted with the VOSviewer tool, which creates connections between relevant terms. The lines in the graph connect individual terms and their thickness reflects the strength of the connections, i.e. the number of publications in which the terms occur together. The thicker the line, the stronger the link between terms (Van Eck and Waltman, 2019).

Figure 1. *Co-occurrences analysis of keywords „accessibility" and „bicycle"; 51 papers published in Web of Science.*



Source: *Own study.*

Figure 1 depicts the co-occurrence analysis of key terms, revealing five major thematic clusters, each representing distinct research areas on transport accessibility and cycling. The red cluster (8 items) with the term 'bicycle' as a focal point is

concerned with bicycle systems, such as bike rentals, and their impact on the environment and users. Research in this group analyses the optimisation of the location of bicycle stations and user behaviour. The strong link between 'bicycle' and 'station' shows the importance of cycling infrastructure in increasing transport accessibility (Arellana *et al.,* 2020).

This cluster also highlights the environmental dimension of cycling in the context of sustainable development (Da Silva *et al.,* 2020). The green cluster (5 items), centred around the term 'accessibility', focuses on analyses of transport accessibility, especially in relation to distance and integration with public transport. This approach often uses GIS technologies to assess spatial accessibility and its impact on different user groups (Zhou *et al.,* 2024; García-Palomares *et al.,* 2012).

The strong links between 'accessibility' and 'analysis' indicate that this research is analytical in nature (Zhou *et al.,* 2024; Da Silva *et al.,* 2020; Zuo *et al.,* 2020). The blue cluster (5 items) with the terms 'city' and 'pedestrian' emphasises the importance of transport accessibility in urban space, especially for pedestrians.

These analyses may consider the impact of accessibility on urban development, the functioning of public spaces and the quality of life of residents. The yellow cluster (4 items) includes terms such as 'population', 'walking' and 'scenario', indicating a focus on walking accessibility and demographic analyses.

These studies may consider different scenarios related to population density or socio-spatial structure, showing how accessibility varies according to local conditions (Zhao, 2014). The purple cluster (3 items), centred around the term 'model', may focuses on modelling cyclists' behaviour and their interaction with transport infrastructure. This research uses mathematical and simulation tools to predict the effects of different transport solutions (Gu *et al.,* 2024; Mahajan and Argota Sánchez-Vaquerizo, 2024).

Each cluster presents a different aspect of accessibility research in the context of cycling, from spatial and infrastructural analyses to theoretical modelling and demographic research. The interconnectedness of the clusters highlights the interdisciplinary nature of this research and its importance in shaping more sustainable transport systems.

2.2 European Bike-Rental Schemes

The first bike sharing system started in Amsterdam in 1965 (Midgley, 2011). The basic assumption behind the creation of this type of micro-mobility was the active promotion of ecofriendly transportation solutions to reduce traffic congestion and emissions. Bike-sharing systems, and also bicycles itself, are an alternative which can provide short-distance trips, but also enhance connectivity to public transportation networks (Nath and Rambha, 2019; Mahajan and Argota Sánchez-Vaquerizo, 2024).

They can provide a cheaper and environmental friendly mobility solution instead of car usage, and on the other hand- they can give satisfaction to individuals in relation to traditional public transport systems (Billhardt *et al.*, 2021; Kabra *et al.*, 2020).

From the perspective of the article, it is essential to illustrate specific systems that demonstrate how bike-sharing operates. This is particularly important in terms of the availability and accessibility of this mode of mobility. These systems rely on various strategic and operational management decisions and policies, which include fleet size, vehicle distribution, and the operational framework.

According to Nath and Rambha (2019), we can distinguish: (1) traditional model, (2) non-automated model with bicycle docking points, (3) automated model with bicycle docking points- station-based, and (4) free floating. Those systems might be also integrated into the generations of bike rental system development (Table 1).

Most of existing bike-sharing systems are fourth or fifth generation, in which dockless bikes are used in a free-floating or station-based scheme. Those types of systems have lower setup costs which makes them easier to set up in many cities.

Table 1. *Types of bike-sharing systems.*

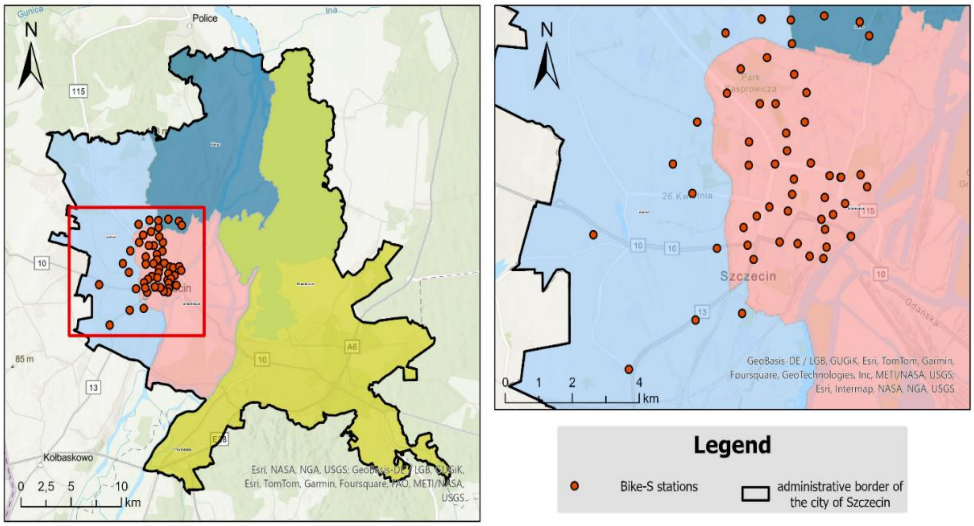
	Traditional system		**Non-automated model with docking points**	**Automated, station based model**	**Free floating model**
	First generation	**Second generation**	**Third generation**	**Fourth generation**	**Fifth generation**
Features of the system	– non automated – free of charge – distinct bicycles – unlocked – no stations	– non automated – coin-deposit system – locks – distinct bicycles – usage free of charge – docking stations	– non automated – usage of smart cards – distinct bicycles – locks – docking stations – access booths	– automated – usage of smart cards – docking stations – introduction of e-bikes – real-time availability – access with usage of mobile app – optional GPS tracking	– automated – dockless systems – e-bikes – access with usage of mobile app – GPS tracking
Year of introduction	From 1965	From 1991	From 1996	From 2005	From 2015

Source: *Authors' elaboration based on Kłos-Adamkiewicz, 2014; Nath and Rambha, 2019.*

2.3 The Bike Rental Scheme in Szczecin

The bike rental scheme in Szczecin was firstly launched in late summer of 2014. From the very beginning its name was “Bike-S”. There were 33 stations including 360 bicycles. Then in 2016, 47 additional stations were added with 344 bikes, which gave in total 78 stations. 52 Bike-S stations were located on the left bank of the city (where the city centre is located) (Figure 2), and additional 26 on the right-bank (NiOL, 2024).

Figure 2. *Location of 52 Bike-S station on the left bank of the city*



Source: *Authors’ map prepared in ESRI ArcGIS Pro 3.3.2 software.*

Effectiveness and user satisfaction were the main challenge since the bike-rental scheme was created. And so was the availability of bikes (and also, at the very beginning- slots for returning rental bikes) along with exact location of the stations. The starting point for Bike-S stations location was covering the area of the city centre, having in mind, that from the operational point of view, and at some stage- the whole system may face the unbalancing problems (Billhardt *et al.*, 2021), when available bikes are concentrated at certain areas (and certain times of a day), whereas in other areas few or no bikes are available.

This problem, unfortunately is in most of the cases inevitable, and so it was in the case of Szczecin. Proper bike balancing mechanism was solved by using dedicated vehicles that moved bicycles from full to empty stations. In order to mitigate those problems- there is a need for creation of optimal and efficient system that also meets the requirements in terms of transport accessibility.

3. Research Methodology

The primary goal of this research is to assess the transport accessibility of the Bike-S bike-sharing system in Szczecin, focusing on spatial coverage, distribution of stations. The approach relies heavily on Geographic Information System (GIS) tools, as these enable detailed geospatial analysis, which is essential for evaluating transportation systems in an urban context. GIS provides powerful tools for analyzing spatial patterns, measuring accessibility, and identifying gaps or underserved areas in the bike-sharing system.

The development of accessibility analysis in this paper was prepared in ArcGIS Software. The *Feature Analysis*, including *Use Proximity* tool and in detail: *Creation of buffers* (ArcGIS Pro desktop version) and *Creation of Drive-Time Areas* (ArcGIS Online) will be used.

In ArcGIS Pro, the *Creation of Buffers* tool was employed to generate areas around each station that represent various distances—300 meters, 600 meters, and 1000 meters. These buffer zones help identify the coverage areas around each bike station, allowing for an assessment of the system's spatial reach. The choice of these distances was based on public transportation accessibility standards in Szczecin, as well as the aim of this study to assess short-distance mobility solutions.

ArcGIS Online was used to conduct *Drive-Time Area Analysis*. This analysis takes into account the city’s street network to calculate the areas that can be reached from each bike station within specified walking distances or times. This analysis was more realistic than the buffer analysis because it accounted for actual pathways rather than straight-line distances.

The drive-time areas were calculated for three distances: 300 meters, 600 meters, and 1000 meters. Additionally, a 12-minute walking time threshold was introduced based on the city's public transportation standards, which set a maximum walking time of 12 minutes to reach a public transport stop (Higgins *et al.*, 2022).

The results from both the buffer and drive-time area analyses were visualized using maps generated in ArcGIS Pro and ArcGIS Online. These maps served as the foundation for understanding the spatial coverage and gaps in the system. They show the locations of bike stations and the areas that fall within each buffer zone. The maps also display the drive-time areas around each station, indicating which parts of the city can be accessed within the specified time or distance constraints.

By visualizing these results, the study could identify areas of good coverage and areas where the bike-sharing system does not provide sufficient access. These maps also allowed for the identification of gaps in the system, particularly in the western and northern parts of the city, which were underserved by bike stations.

The analysis focuses on the left bank of Szczecin, where the city centre is located. This area was chosen because it has a higher population density, better connectivity to public transport infrastructure, and the highest concentration of bike-sharing stations. Additionally, the left bank is the core urban area of Szczecin, where most daily commuting and short-distance travel occur. These factors make it an ideal location for studying the effectiveness of the bike-sharing system.

Preparation of the analysis was based on four steps: (1) preparation of the list of Bike-S stations in Szczecin, (2) obtaining geographic coordinates for each station, (3) creation of a map with a layer presenting the Bike-S system, (4) usage of ArcGIS Proximity Tools to gather information about buffers and drive-time areas for the analysed stations.

4. Research Results

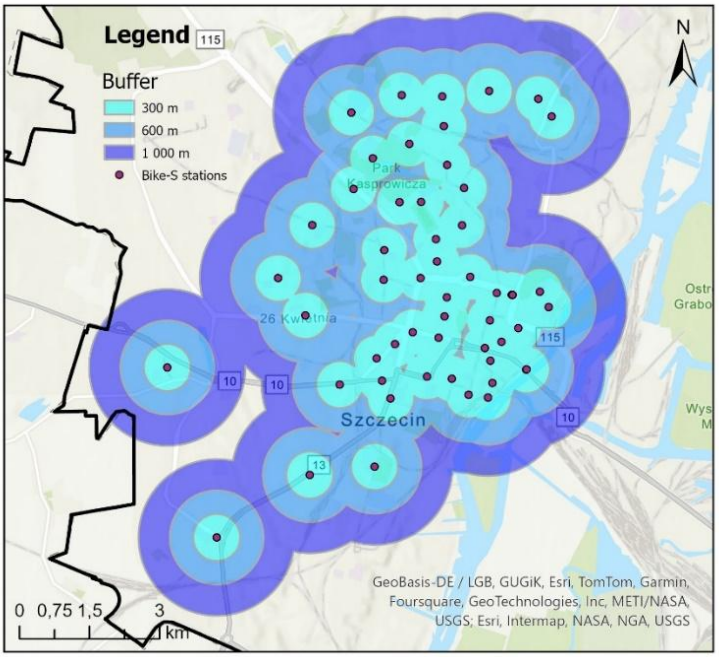
This section is divided into two sub-sections: (1) Coverage and blank spots identification- buffer perspective, and (2) Bike-S drive-time areas assessment. The starting point for the accessibility analysis were the standards of time and distance of walking to public transport stops introduced in Szczecin in 2014 based on a document: "*Sustainable development plan for public transport for the city of Szczecin for years 2013-2025*" (Kłos-Adamkiewicz *et al.,* 2014).

According to this document- the maximum time to reach a public transport stop should not exceed 12 minutes, and also distances between public transport stops should not exceed 600 m (optimum at 300-400 m) in an urbanized area, outside the urbanized zone this distance should be limited to 1000 m. As there are no accessibility standards for distance between bike- sharing stations, the authors used the time and distance for public transport.

4.1 Coverage and Blank Spot Identification- Buffer Perspective

The first analysis was made with the ArcGIS Pro tool called *Creation of buffers*. A buffer in GIS is a defined zone or area created around or within a geographic feature such as point, line or polygon. In this case, the buffers cover the area of 300, 600, and 1000 metres, to show transport accessibility by the distance in a straight line from each of the bike rental stations in Szczecin (Figure 3).

Figure 3. *Buffers from the Bike-S stations- 300, 600 and 1000 m*



Source: *Authors' map prepared in ESRI ArcGIS Pro 3.3.2 software.*

The results from the buffer analysis show that the central part of Szczecin, particularly the area around the city centre, is well covered by the bike-sharing system. Stations are located within a 300-meter distance from each other in most parts of the city centre, ensuring easy access for users.

However, some peripheral areas, particularly on the west, have limited coverage. The station- "Kwiatowa," the westernmost point of the system, is isolated from the rest of the network, with only a small overlapping area in the 1000-meter buffer zone. Similarly, the station- "Rondo Uniwersyteckie-Kampus US," located in the southwestern part of the city, although somewhat distant, still falls within the 1000-meter buffer, ensuring access to the broader network.

The buffer analysis also highlighted areas with no bike-sharing stations. These gaps are most prominent in the northern and western parts of the city. While these regions are beyond the 1000-meter buffer zone, it is important to note that the Bike-S system was initially designed as a last-mile solution to complement the city's public transport, primarily serving the city centre and surrounding areas. Therefore, these areas outside the 1000-meter buffer zone are not within the system's primary service area, reflecting the initial strategic planning of the network.

4.2 Bike-S Drive-Time Areas Assessment

The second analysis shows walking-distance areas, which was the analysis based on the tool called: *Creation of Drive-Time Areas*, which makes possible to show also walking-distance and walking-time based on existing street network. This tool uses Esri Service Areas to calculate the area that can be reached within a specified travel time or distance along a street network based on travel mode.

However, unlike in the previous analysis, this one was prepared in ArcGIS Online, as it required up-to-date road network scheme on selected area, in this case- the city of Szczecin. The walking-distance analysis was prepared for 300, 600 and 1000 m (Figure 4), and walking-time analysis for 12 minutes (Figure 5).

Figure 4. *Drive-time areas for the Bike-S stations- 300, 600 and 1000 m*

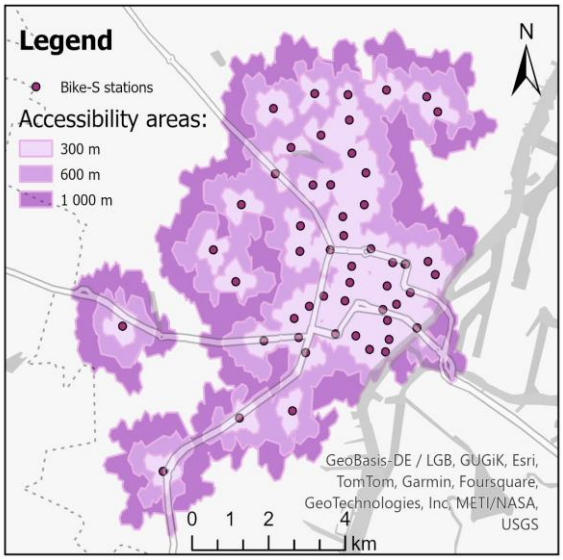
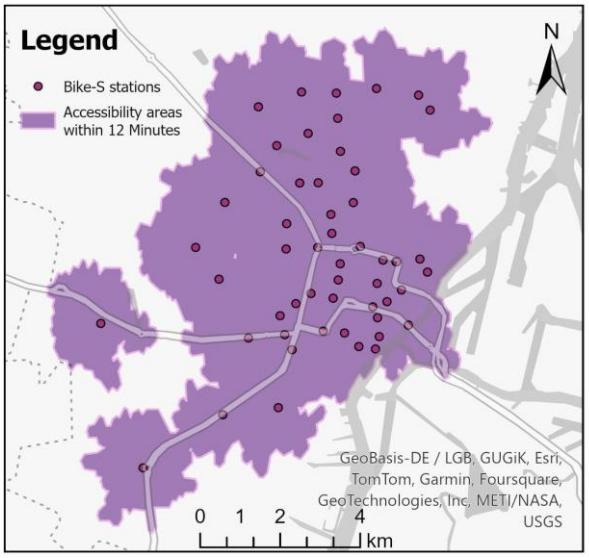


Figure 5. *Drive-time areas for the Bike-S stations- 12 minutes*



Source: *Authors' map prepared in ESRI ArcGIS Pro 3.3.2 software.*

The results from the drive-time area analysis showed that most of the city centre is well-served by the Bike-S stations, with accessible coverage within the 300-meter and 600-meter walking-distance zones. As with the buffer analysis, the station- "Kwiatowa" remains an outlier in terms of distance, as it is located more than 1000 meters from other stations based on the actual street network. Nevertheless, it still falls within the 1000-meter drive-time zone, ensuring connectivity to the rest of the system.

In terms of walking-time analysis, the 12-minute walking threshold was met for most of the city centre, indicating that users can reach bike-sharing stations within the prescribed time. However, as with the buffer analysis, there were gaps in the

western and northern parts of the city. These gaps reflect areas with no stations or insufficient access, especially between the distant stations, like “Kwiatowa” and “Rondo Uniwersyteckie-Kampus US.”

The drive-time and walking-time analysis highlighted a key gap between the city centre and the western part of Szczecin. These areas, which are outside the 1000-meter walking-distance zone, exhibit a lack of bike-sharing stations and would benefit from additional stations to bridge the gap. These blank spots may hinder users from easily accessing bikes, especially in peripheral areas that could benefit from last-mile solutions.

5. Discussion

This study analysed the transport accessibility of bike-sharing system in Szczecin, called Bike-S, with the usage of GIS-based tools. The findings reveal the areas of both strong coverage and significant gaps in the system’s transport accessibility. Bike-S demonstrates potential for enhancing micro-mobility in Szczecin, it highlights the need for strategic development and optimization of station locations for further improvement of overall coverage and connectivity.

The concentration of stations, mostly based in the city centre, may create accessibility disparities, especially in peripheral areas, underscoring the importance of equitable distribution of resources.

Furthermore, as the study focus on the left bank of Szczecin, it limits the generalizability of findings to the entire urban area. For sure, there is a need for further research that would:

(1) expand the analysis to encompass both left and right bank of the city, no matter the role it plays in local economy,
(2) investigate the temporal dynamics of bike-sharing mobility patterns and user behaviour,
(3) integrate user data and make in-depth exploration of the interplay between bike-sharing system and other modes of transport to fully understand the role of Bike-S in Szczecin’s urban mobility landscape,
(4) include demographic statistics, including: population density for intersectional analysis,
(5) conducting a cross-sectional analysis which takes into account geographical data and statistics including i.e. rentals and returns at individual stations.

6. Conclusions

From the point of view of accessibility analysis- the distribution of the bike-rental stations in Szczecin is even, apart from one gap, which is located away from the city centre, on the boundaries of the entire system. According to the public transport

standards in the city, which, however, do not directly concern bicycles, it can be assumed that the requirements for the transport accessibility of the city bike system are met. In its assumption, Bike-S main aim was to cover the spatial scope of the city centre and the nearest areas and was supposed to constitute a last mile solution for public transport or sustainable solution in the field of individual transport modes over short distances.

Bike-sharing systems are becoming an integral part of sustainable transport systems in the city, along with public transport. On the example of Szczecin, it can be seen that provision of a sufficiently large number of bicycles at properly distributed stations can bring effects on a wider scale.

This analysis covers the station-based with docking points system, which was running until 2022. Since 2022, the whole system went through major changes, including transformation into fourth-generation scheme, with bicycles equipped with GPS, which allows to rent and return the bicycles outside the parking zones- as long as user is within the area where the bike-share system operates.

This analysis, deliberately made ex-post, when the new generation of Szczecin's bike is running, shows, that the whole project, from the very beginning, is heading in the right direction. This paper shows, that the station based, docking system was good, but there could be steps undertaken to make it even better.

That is why, the city has chosen to move from station oriented to dockless system-area oriented. The proper transport accessibility of the stations, the right amount of bicycles and also, without a doubt the city's financial support makes the whole bike-share system in Szczecin work properly.

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