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Elżbieta MACIOSZEK[1], Irena JURDANA[2]

BICYCLE TRAFFIC IN THE CITIES

Summary. For many years in many Western Europe countries, cycling has been associated with not only recreation and tourism but has equally gained an important function as a means of transport used in everyday commuting to work, study and entertainment. The bicycle appears to be a very good alternative to motor vehicles that produce exhaust fumes and create congestion on road transport networks. Not only is the bicycle environmentally friendly and takes up little space in road transport networks, but also, the time of bicycle travel is often competitive in relation to travel made by private car or public transport. This article presents the characteristics of the bicycle infrastructure and services offered in selected cities in the world and Poland, as well as the issues of bicycle counters as sources of data on bicycle traffic volume, along with an exemplary analysis of this type of data.

Keywords: bike, bicycle traffic volume, road transport, transport, traffic engineering

1. INTRODUCTION

In many Polish cities, as in many cities around the world, the number of cyclists is gradually increasing. To improve the safety and comfort of cycling, it is necessary to build an appropriate infrastructure dedicated to cyclists. In the case of the absence of such infrastructure, cyclists

[1] Faculty of Transport and Aviation Engineering, The Silesian University of Technology, Krasińskiego 8 Street, 40-019 Katowice, Poland. Email: elzbieta.macioszek@polsl.pl. ORCID: https://orcid.org/0000-0002-1345-0022
[2] Faculty of Maritime Studies, University of Rijeka, Studentska Ulica 2, HR-51000 Rijeka, Croatia. Email: irena.jurdana@pfri.uniri.hr. ORCID: https://orcid.org/0000-0002-3287-1383

share the space with motor vehicles, which travel at a much higher speed than them. Designing an infrastructure dedicated to cyclists should consider the technical possibilities of both the bicycle and the cyclist. The bicycle user performs the bicycle's driving functions and drives the cycle at the same time.

The main reasons for the increase in interest in the bicycle in recent years include the ease of use, no need for additional licenses, as well as the fact that the use of the bicycle does not require large expenditures and is easy to maintain. Moreover, traveling by bike is comfortable and attractive. The bicycle is mainly used for short distances. Slightly over 80% of all bicycle journeys are shorter than 5 km [28].

In addition to daily trips to work, school or shopping, the bicycle also plays an important role in recreational travel. In recent years, the number of recreational trips by bicycle has been systematically growing in all European countries. Given the values of the surrounding landscape, attractive bicycle routes are also of key importance, and this is an important element in promoting recreational bicycle journeys.

Designing bicycle infrastructure brings many benefits to users; namely, it contributes to facilitating car-free travel, improving traffic safety, reducing travel times in the city center, improving psychophysical conditions, reducing travel costs, and increasing the flexibility of traveling. On the other hand, the benefits that the organizer of bicycle traffic gains include a change in the division of transport tasks toward increasing the share of car-free travel, the possibility of transforming the space of streets and squares, reducing investment and operating costs related to the transport system, creating a positive image of the city, open to promoting ecological forms of transport, as well as improving public health.

This article aims to characterize urban cycling. It consists of five sections. After the introduction, the second section presents and characterizes the bicycle network with services offered in selected cities around the world. Then the third section presents the bicycle network along with the services offered in selected cities in Poland. While section four contains the problem of bicycle counters as sources of data acquisition on bicycle traffic volume, together with the analysis of this type of data. Finally, the fifth section submits conclusions from this research.

2. CHARACTERISTICS OF THE BICYCLE NETWORK TOGETHER WITH THE OFFERED SERVICES IN SELECTED CITIES IN THE WORLD

In many cities around the world struggling with the problem of excessive car traffic volume, bicycle traffic is promoted not only because of the obvious health benefits for the cyclist but also due to the promotion of the policy of sustainable transport development, in which the bicycle is one of the equal means of transport in travels around the city as well as a means of transport for the first and last mile in commuting to the initial and final stops of public transport.

Amsterdam (the Netherlands) with its urban agglomeration has over 1.1 million inhabitants and is considered to be the most bicycle-friendly city in the world. The city is famous primarily for a large number of bicycles and a very good bicycle infrastructure. In Amsterdam, it is recognized that every street is suitable for cycling. According to the data, the total length of all designated bicycle routes in the Netherlands exceeds 15,000 kilometers. Moreover, it is estimated that there are more bicycles in the city than there are inhabitants. According to statistics, there are one and a half bicycles per inhabitant of Amsterdam. About 70% of all traffic volume in the city center is constituted by cycling, and in the agglomeration of the city, it accounts for less than half of all journeys. In the Netherlands alone, almost 30% of all journeys

are made by bicycle. Amsterdam is also known as the largest cycling science and culture center in the world. Many developed guidelines, recommendations, and proven practical solutions have been developed in the Netherlands. In Amsterdam, there are also numerous characteristic bicycle parks called Fietsenstalling. It is estimated that there are around 250,000 total bicycle parking spaces in Amsterdam [14]. In the Netherlands, there are also bicycle taxi services known as Amsterdam Bike Taxi, which, along with the increasing congestion on the street network and a significant reduction in car traffic volume in the city center, is becoming increasingly popular. However, bicycles also fall victim to vandalism. It is estimated that about 80,000 bicycles are stolen in the city each year, and 25,000 are lost to the city's sewers every year [39].

Copenhagen (Denmark), thanks to a well-developed network of bicycle routes, is also considered one of the most bicycle-friendly cities in the world [1]. Often, the traffic lanes for cyclists are separated from the road by a green belt, and in many places, there are also special traffic lights for cyclists. Investments in infrastructure dedicated to cyclists are constantly being carried out in the city, including work on the system of fast bicycle paths, which will be designed to enable quick and efficient cycling over longer distances. Ultimately, this system will cover a total of over 100 km of bicycle paths [19]. Every day, cyclists in the city cover 1,000,000 km, and over 45% of journeys are made by bicycle. In addition, it is indicated that the inhabitants of Copenhagen make around 50% of their journeys to work by bicycle. In Copenhagen since 2014, there is also a public bike rental system (Bycyklen). Statistics on road accidents indicate that the level of traffic safety offered to cyclists is at a very good level. For one victim of a group of cyclists in traffic in the city, the average cyclist traveled 4.4 million kilometers [10]. Furthermore, statistics show that Copenhagen has more bicycles than people, five times more bicycles than cars, and 400 km of bicycle lanes. On average, 20,000 bicycles are stolen in Copenhagen in one year [24]. The small number of bicycle parking spaces has a significant impact on theft. For a city with about 600,000 bicycles, the number of bicycle stands does not exceed 50,000. The city plans until 2025 to expand the infrastructure for parking bicycles. Currently, the city is known for its well-developed cycling culture. It is believed that there are so many cyclists in the city that the existing infrastructure often exceeds its capacity.

Melbourne (Australia) has an extensive network of dedicated cycle paths and bicycle lanes that are used for daily commuting, leisure and sports centers. However, the share of cycling accounts for less than 2% of all trips in the entire Melbourne metropolitan area (2016 data) [5]. In the 1990s, Australia and New Zealand introduced the obligation to use helmets while cycling, which contributed to a visible decrease in the number of trips made by bicycle. In Melbourne, the bicycle is used mainly for recreational and health-promoting purposes. The length of bicycle routes in Melbourne is over 1,900 km (2016 data) [4, 15, 16]. Many bicycle paths run along rivers, highways and railway lines. Since 2010, the city has operated the Melbourne Bike Share system of city bikes, which was equipped with a fleet of 600 bikes and 51 stations. Melbourne Bike Share was one of two such systems operating in Australia. On November 30, 2019, the government of the state of Victoria decided to end the Melbourne Bike Share operation.

Toronto (Canada) has been established as a partner city of the cycling capitals of the world, such as Amsterdam and Warsaw. Toronto, like many other North American cities, invests in modernizing infrastructure dedicated to cyclists. Along with the expansion of the infrastructure dedicated to cyclists, the number of cyclists has grown steadily. In 1975, the "Toronto City Cycling Committee" was established to promote initiatives related to cycling and bicycle safety [12, 37]. Following the assumptions of the bicycle road network development plan titled "Toronto Bike", it plans to build a suburban network of bicycles, off-road paths, signposts, and parking lots for bicycles. Another important element of this plan is educating citizens to reduce

the number of collisions and falls and promoting an increase in the number of people cycling [37]. The city of Toronto also offers Can-Bike courses to its inhabitants. The course provides information on how to safely cycle in regular city traffic. In Toronto, since 2011, the Bike Share Toronto bicycle rental system has been in operation, consisting of 2750 bicycles and 270 stations (data from 2017) [21, 37]. All Toronto buses have bike racks to store bikes in, and transportation of bikes is also permitted on the subway outside of the morning, and evening rush hours. Additionally, "GO Transit" (Ontario's Massive Public Transport System) also provides bicycle racks on all bus routes and allows bicycles to be transported on trains during off-peak weekdays. Since 2008, the transport of folded bicycles in public collective transport is allowed.

The bicycle in London (United Kingdom) is a very popular means of transport and an idea for spending free time. In 2010, Transport for London launched the "Santander system" city bike rental. About half a million people use bike rentals every year. In London, folding bikes can be transported by almost all means of public transport, while full-size bikes can be transported on selected routes during off-peak hours. London has numerous bicycle parking facilities. The most common are bicycle racks, sometimes they are lockers available at many public transport stops. Daily cycling trips in London increased by 170%, from 270,000 in 1993 to 730,000 in 2016 [25]. Moreover, the number of fatal and seriously injured victims of road accidents involving cyclists has decreased [22].

Paris (France) is steadily increasing its network of public bicycle paths. There are currently over 700 km of bicycle routes in Paris, including cycle paths, and bicycle lanes. The length of the network of the paths themselves is 371 km (data from 2020) [8, 30]. Statistics show that bicycle traffic volume was very sporadic in the 1980s, car traffic volume was 85 times greater than bicycle traffic volume; however, it started to increase only in the 1990s. Currently, Paris is striving to belong to the group of cities called the world's bicycle capitals, investing every year in the development of bicycle infrastructure [29, 30]. Since 2016, "The Paris Respire Program" has been operating in the city, which is characterized by the fact that some districts are closed to motorized traffic on Sundays, and public holidays from 10 a.m. to 6 p.m., and some districts are open only on weekdays, and Saturdays for motorized traffic, and a few are closed only on the first Sunday of each month. The program also includes the closed roads on the Seine, Marais, Canal Saint-Martin, and Montmartre, as well as roads in other parts of the city [31]. These districts have access, inter alia, bicycles, taxis, buses and vans with a speed limit of 20 km/h. In Paris, the municipal bicycle rental system, Vélib, has been operating since 2007. The city-owned Cyclocity system is operated by JCDecaux. The network is available in Paris and 30 municipalities in and around Paris. The system offers a fleet of 14,000 bicycles at 1,230 stations. It attracts an average of more than 86,000 users per day [30]. The 5,122 km long European cycle route EuroVelo 3 passes through Paris, known as the Pilgrim Trail, which connects the city of Santiago de Compostela in Spain with Trondheim in Norway.

3. CHARACTERISTICS OF THE BICYCLE NETWORK TOGETHER WITH THE OFFERED SERVICES IN SELECTED CITIES IN POLAND

In Poland, in recent years, the intensity of bicycle traffic has increased significantly, but it is still far from Polish cities to other European or world cities known as the world's bicycle capitals. In the further part of this section, a few selected Polish cities are presented, in which a significant development of the bicycle road network has been observed in recent years.

In Warsaw, the bicycle network is approx. 645 km (including 475.5 km of bicycle paths, 79.5 km of pedestrian and bicycle routes, 44 km of bicycle lanes and 46 km of streets with a bicycle lane). The newly built sections are primarily designed to connect the existing routes into a coherent network of bicycle paths to enable functional and comfortable cycling over longer distances [2, 23]. In Warsaw, constant supervision, and investment activities aimed at the maintenance and ongoing repairs of the existing infrastructure are visible. Compared to other Polish cities, the quality and equipment of bicycle routes in Warsaw are very good [32]. In Warsaw, there is the Veturilo city bike system, considered to be the largest bicycle system in Central and Eastern Europe. Veturilo is constantly being expanded. In this system, there are over 390 stations and over 5,700 bicycles available in total, including electric bicycles, tandems, and children's bicycles [36, 40]. In 2018, bicycles were rented over 6.4 million times, and in 2019 over 5.9 million times. However, during the pandemic, the number of loans was lower [2].

There are approximately 170 km of bicycle paths in Lublin (2019), including dedicated bicycle paths, common pedestrian and bicycle paths, bicycle lanes, and counter-lanes. The first bicycle paths in Lublin were built in the nineties of the twentieth century. In recent years, the city authorities have adopted several strategic documents regarding the development of bicycle traffic. In 1997, the city council issued a resolution on the principles of communication policy, and in 2000, "The Study of the Conditions and Directions of Spatial Development", which also included bicycle transport. However, according to the Study of the Conditions and Directions of Spatial Development, the program of building a network of bicycle paths was to serve mainly tourists and recreational purposes [34]. In the years 2010-2015, five strategic documents concerning the bicycle policy were published, including the resolutions of the City Council: the Bicycle Policy of the City of Lublin and the Concept of the Development of Bicycle Transport in the City of Lublin [6]. Lublin's transport policy assumes the sustainable development of transport, and its goal is to achieve, by 2025, at least 15% of the share of bicycle traffic in the total number of trips in the city [7]. Lublin also has a public city bike rental system called "Lubelski Rower Miejski", which was officially opened in 2014 and consisted of 40 bicycle stations, and 400 bicycles. Currently, this system consists of 96 stations, 951 bicycles, including 2 stations, and 20 bicycles for children. In the neighboring town of Świdnik were 5 stations and 41 bicycles [17, 26]. The operator of the Lubelski Rower Miejski system is Nextbike Polska Sp. z o.o.

In turn, in the city of Gdańsk, the network of bicycle routes has a total of 734 km (according to data from December 2019). These routes include dedicated cycle paths of 127.5 km; pedestrian and bicycle routes with priority for pedestrians, 18.2 km; pavements with allowed bicycle traffic, 32.2 km; bicycle lanes on the road, 9.4 km; bus and bicycle lanes, 0.5 km; walking and driving routes, 13.7 km; streets with calm traffic, with a maximum permissible speed up to 30 km/h; 530.5 km (percentage of the total length of public roads - 64.4%), and one-way streets, which allowed bicycle traffic in the opposite direction 54.5 km (221 streets) [13, 28]. The network of Gdańsk bicycle paths is considered to be one of the most extensive in Poland. There are 26 bicycle counters installed in Gdańsk, which count the passing two-wheelers using the induction loops placed in the pavement. Two of these meters are equipped with electronic displays informing about cycling data at the measurement site. Data from all measurement points are summed up every day and sent to the GSM network of internet servers. These data are presented online on the website of the Active Mobility Department of the Gdańsk City Hall [18]. In 2019, from March to October, a system of maintenance-free city bike rentals operated in Gdańsk. The system included 660 stations and a fleet of over 4,000 bicycles. It was supposed to subtract the Tri-City area (Gdańsk, Gdynia, Sopot), and its operator was NextBike.

Poznań has a very rich cycling history. In the interwar period, bicycle traffic in this city accounted for more than half of all journeys made. This share was, therefore, higher than the share in cities considered to be bicycle-friendly, such as Copenhagen or Amsterdam. However, with the development of the automotive industry, many bicycle lanes have been closed and designated for parking spaces [11]. In 2018, Poznań had approx. 175 km of bicycle paths, pedestrian and bicycle routes, and bicycle lanes. Currently, there are 13 self-service bicycle repair stations in the city and 6 guarded bicycle parking lots (data from 2018). The main problem of the bicycle route network in Poznań is the lack of continuity and coherence of the network. This difference is most visible in the downtown area and in the city center, where the space for bicycle traffic is dominated by car traffic. In Poznań, a system of unmanned city bike rentals, "Poznań City Bike", has been operating since April 2012 (the operator is Nextbike Polska Sp. z.o.o.). The system consists of 113 stations and 1,227 bikes (as of 2018) [35].

Another city in which a significant development of bicycle infrastructure has been visible in recent years is Łódź. Currently, there are 188 km of bicycle paths in the city (2019). Since 2011, as many as 150 kilometers of roads dedicated to cyclists have been created in Łódź. There is a municipal bike rental in the city, which includes 157 stations and 1,584 bikes. In addition, in the Łódź Voivodeship, in 2019, the voivodeship bike sharing system was launched. Stations and parking lots with two-track vehicles are located on the route of the Łódź Agglomeration Railway (Koluszki, Kutno, Łaski, Łowicz, Pabianice, Sieradz, Skierniewice, Zduńska Wola, Zgierzu, and Łódź). As part of the "Rowerowe Łódzkie" program, 125 bicycle stations with 10,000 bicycles are to be built [33].

In 2019, the total length of bicycle paths, including pedestrian and bicycle paths, in Białystok was only 128 km. It is not much for such a large city as Białystok. In Białystok, a system of self-service bike rentals called "BIKeR" has been operating since 2014, consisting of 59 stations and 625 bicycles. The system is well run, and the system infrastructure is extensive. Statistically, there are 450 inhabitants of Białystok per vehicle, which is a very good result compared to other Polish cities. Additionally, there are 0.62 stations per square kilometer of the city (in Poland, only Warsaw has a higher density of stations per square kilometer of land area). This system covers the surrounding towns, such as Kleosin and Ignatki-Osiedle (including 20 bicycles and 2 stations), and the Choroszcz Commune (2 stations and 14 bicycles) [3].

4. CYCLING COUNTERS AS SOURCES OF DATA ON CYCLIST TRAFFIC

A bicycle counter is a device that automatically counts cyclists moving along the road. Currently installed cycle counters usually operate on the principle of an induction loop mounted under the surface of a lane or a cycle path and from a device that sends data to the server. These counters are not visible to cyclists. The number of cyclists counted is sometimes shown on displays, and sometimes information on the volume of cyclists' traffic can be obtained, for example, from the Municipal Roads Authority and City Offices to which these data are sent.

Sometimes, photocells are also used to count moving cyclists. Roadside counting devices for moving cyclists are installed in many cities in Poland. The first city in Poland to install an abacus with a display was Łódź (2011). So far, automatic cyclist counting systems have been installed, among others, in Szczecin, Tychy, Kraków, and Wrocław. Cyclist counting devices are also used in many cities around the world, especially in those where cycling is promoted, for example, in London, Kopenchaga, and Budapest. Counters are needed to check how cycling is spreading in an area. One of the tasks of bicycle counters is to verify whether the investments carried out in a given area are producing the expected effect. Moreover, they allow, based on

the collected data, to plan the city's transport policy. Due to the bicycle counters, it is possible to determine, among other things, which routes are used for daily commuting to work or school, and which are rather recreational, which routes are used at weekends, and how the traffic volume is distributed at certain times, days, etc., which is part of the wider city strategy that encourages citizens to cycle. In addition, some types of counters can measure the speed of the trip, which can help reduce cycling accidents. Some sources say that the data from bicycle abacus are underestimated. For example, in [20], it was stated that the difference between the number of cyclists registered with the use of the meter and the real one is 6%. The characteristic features of the bicycle abacus include:

- low operating costs of the system,
- data transmission takes place using GPRS technology and the local internet,
- online data transmission from bicycle counters,
- the ability to install a virtually unlimited number of objects in the system,
- event-driven data transmission that guarantees updating the condition of the facilities without incurring unnecessary transmission costs,
- fast, reliable and secure data transfer,
- archiving of data and events of all objects to create analyzes and statistics,
- the possibility of performing both local and remote diagnostics and configuration of the counter,
- easy and generally available access to data on the server due to a dedicated website,
- the incentive to use the bike rental.

The following part of this section presents exemplary results of measurements of the volume of cyclists' traffic from bicycle counters for five measuring points in Kraków (Poland). These data cover the period from January 2017 to January 2020. This period of time was deliberately chosen as it is the period before the COVID pandemic occurred. From 2020, the distribution of the volume of the cyclists' traffic assumed a different character, imposed by restrictions in movement, lockdowns, changes in the work rhythm of employees, and other changes caused by the pandemic. The measurement points along with the period included in the analysis are presented in Table 1.

Tab. 1

The measurements points

No	Name of the measurement point	Date of the measurement
1.	Bulwary	From 01.01.2017 to 03. 01. 2020
2.	Kotlarska Street	From 01.01.2017 to 03. 01. 2020
3.	Mogilska Street	From 01.01.2017 to 03. 01. 2020
4.	Wadowicka Street	From 01.01.2017 to 03. 01. 2020
5.	Wielicka Street	From 01.01.2017 to 03. 01. 2020

The collected data, apart from the values of the intensity of cyclists' traffic, also includes such information as weather conditions, that is, the average, maximum and minimum perceived air temperature, wind speed, and the amount of precipitation.

The heterogeneity of the intensity of cyclists' traffic volume over time should be considered in the context of seasonal, monthly and weekly cycles, although the prevailing weather conditions on the day of the bicycle traffic volume measurements and the day before the bicycle traffic volume measurements are dominant. In Figure 1, the distribution of the intensity of

cyclists' traffic at selected five measuring points in the period from 1 January 2017 to 3 January 2020 is shown. Based on the analysis of these figures, it can be concluded that in each case, each year, the highest values of bicycle traffic volumes are recorded in the period from April to October. During this period, in Polish conditions, the weather is usually favorable for cycling, because then, negative daytime temperatures are not usually recorded, and there is no snowfall or rainfall. On the other hand, from November to March, the recorded intensity of cyclists' traffic volume at all measuring points is rather small. The intensity of bicycle traffic volume is characterized by a different distribution on sunny days and bad weather days. There are also different values of bicycle traffic intensity on weekdays and weekend days.

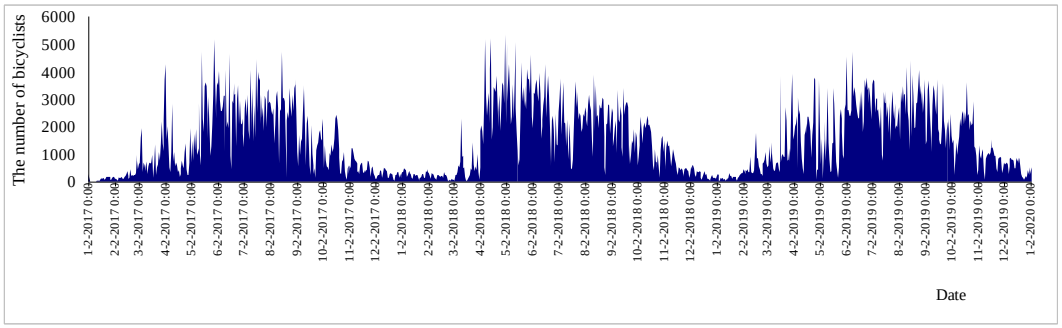
In the next figure, Figure 2, the results of exemplary analyzes that can be performed based on data from bicycle counters are shown. In Figure 2a, the dependence of the number of cyclists on the average temperature of the environment is presented. As seen, there is a relationship between these variables. Due to the significant impact of weather conditions on human health and well-being, it is important to determine the degree of weather impact on the volume of cyclists' traffic. The lowest values of the intensity of cyclists' traffic were recorded at a low, negative average ambient temperature (from -2 to -18ºC), and the highest at moderate average ambient temperatures ranging from about +15 to +20ºC. Further, in Figure 2b, the dependence of the number of cyclists on the amount of rainfall is shown. This relationship also confirms that bicycles are usually used in good weather conditions with no rainfall. Nevertheless, even with low rainfall (up to 2.5 mm per hour), and moderate rainfall (between 2.5 and 7.5 mm), the traffic volume for cyclists is significant. It is only during heavy rainfall (above 7.5 mm per hour) that the intensity of cyclists' traffic is low (but not equal to zero). Figure 2c shows the number of cyclists in relation to wind speed [km/h]. In this case, there is no correlation between these variables. Based on the data from bicycle abacuses, it is also possible to estimate the daily total distance traveled by cyclists (Figure 2d).

5. SUMMARY

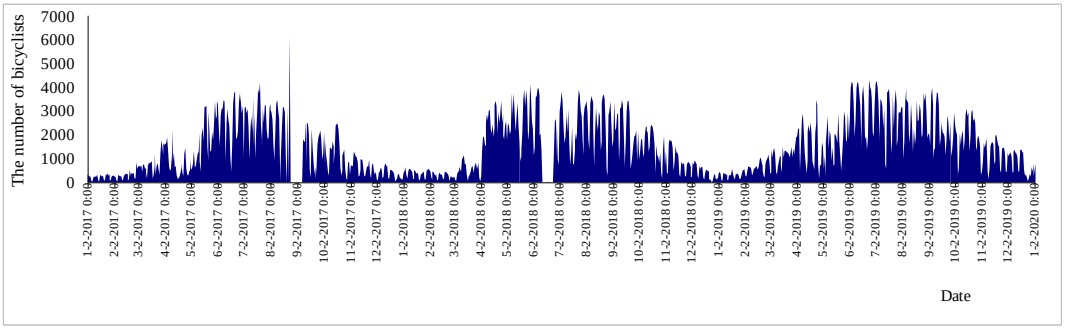
Travel conditions by any means of transport around the city determine its attractiveness and, consequently, translate into the number of users using this means of transport in their daily commuting to their workplace, school or university. The free choice of the means of transport by the inhabitants has prompted discourses about the competitiveness of cars, bicycles, public transport, etc. The authorities of many Western European cities have long noticed great opportunities for shaping the transport behavior of residents by consciously controlling the competitiveness of individual means of transport. This is done by applying, on the one hand, restrictions for some road users (usually cars), and, on the other hand, by promoting other, more desirable transport solutions, for example, cycling.

Cycling is an essential component of transport systems in urban areas. Thus, agglomerations such as Copenhagen and Amsterdam can boast about a 30% share of bicycle trips in the total number of trips. The dynamic increase in the number of cyclists in recent years imposes the obligation to take measures to adapt streets and squares to the growing needs. The high time competitiveness of bicycle transport should be, next to the low land consumption and capital consumption, or a beneficial effect on the health of the inhabitants, an important argument for the rapid development or improvement of the quality of infrastructure for bicycles. Only high-quality bicycle infrastructure can encourage a significant part of the inhabitants to choose a bicycle in their daily journeys while maintaining the appropriate competitiveness of bicycle transport in comparison with car transport.

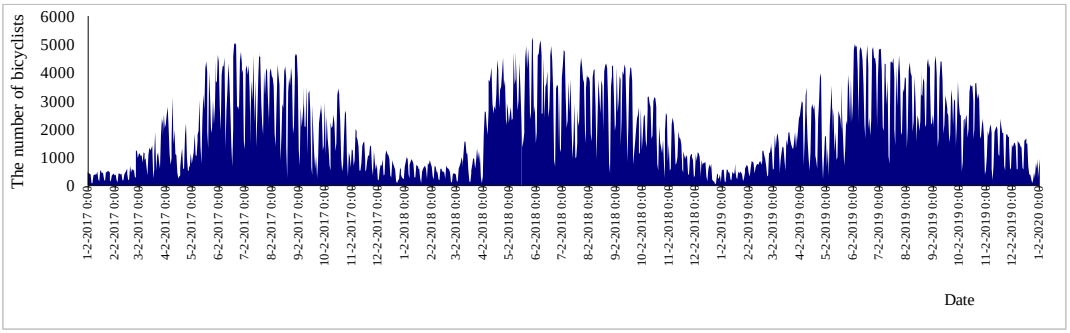
1).



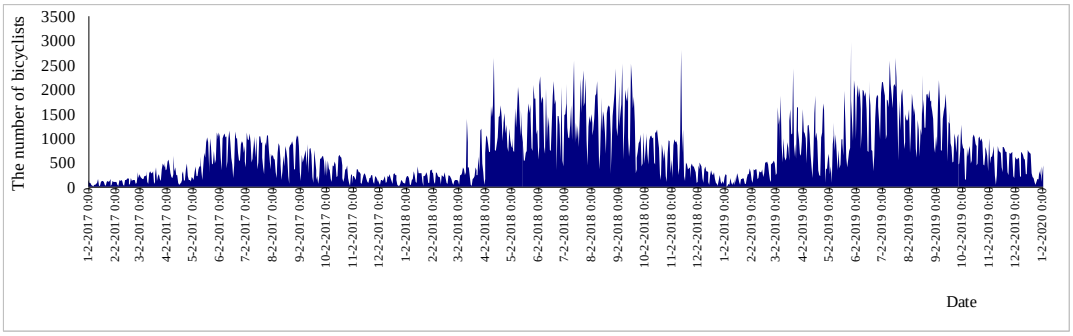
2).



3).



4).



5).

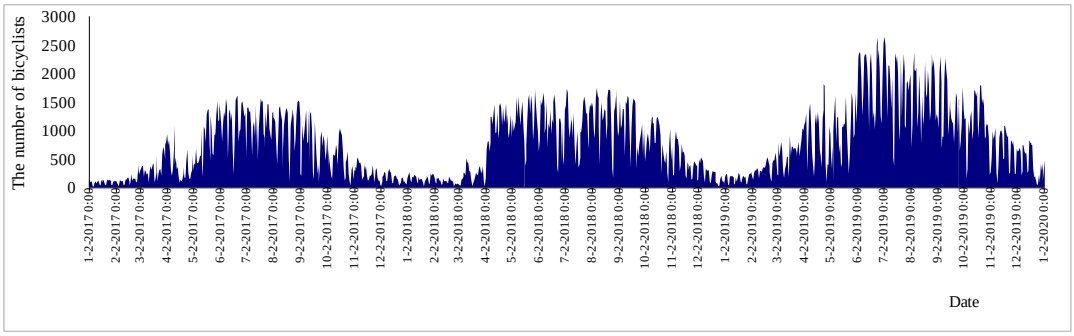
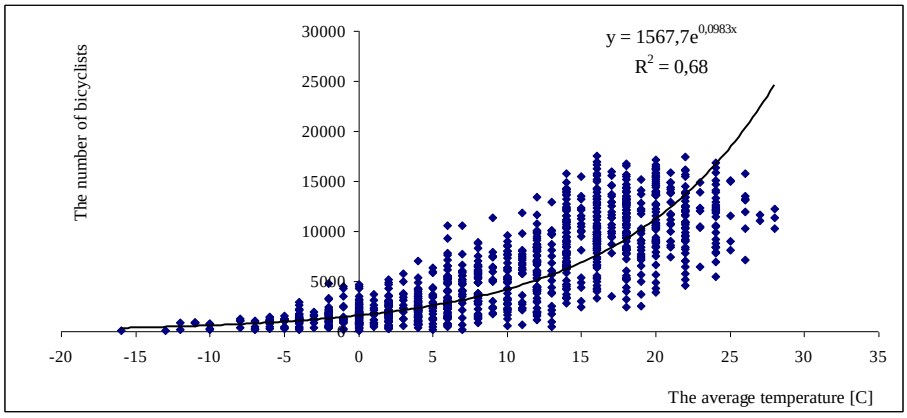
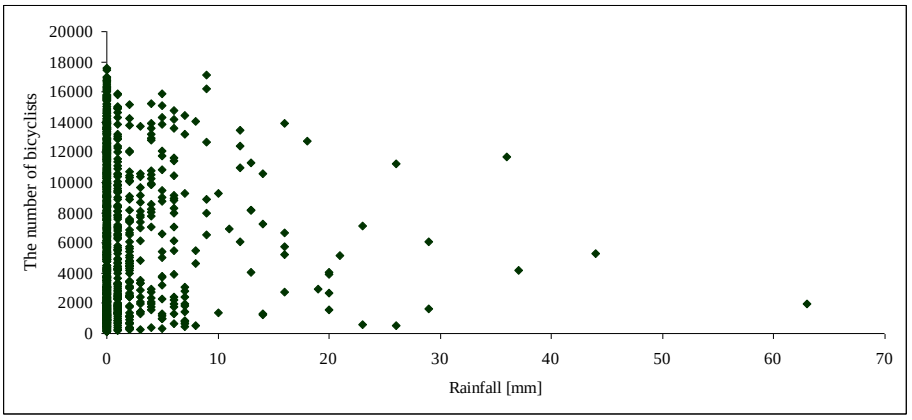


Fig. 1. Distribution of the traffic volume of cyclists at selected measurement points
Source: Author's research based on [9]

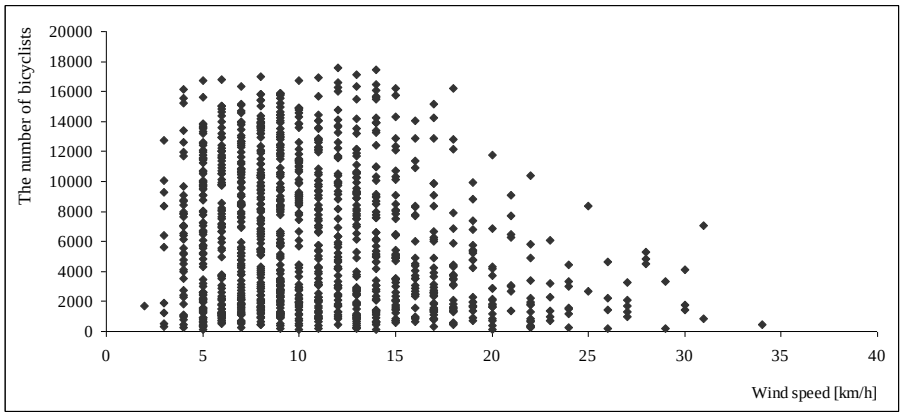
a).



b).



c).



d)

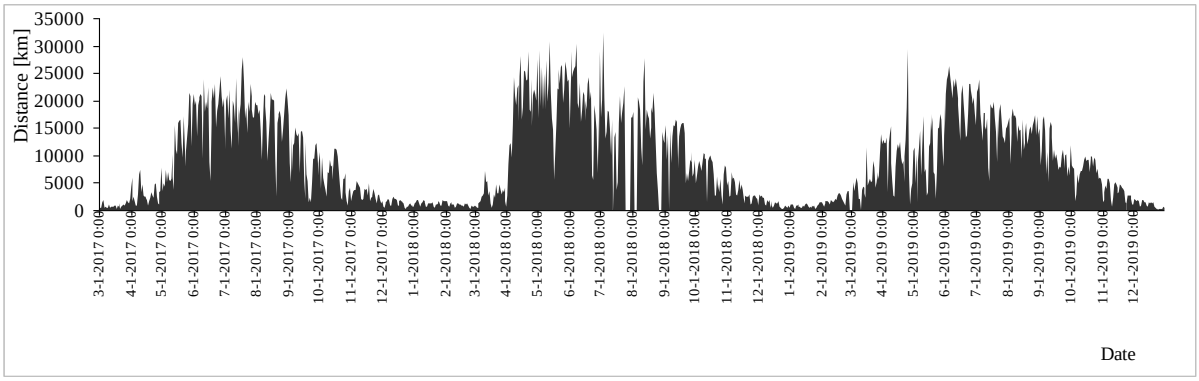


Fig. 2. Distribution of the number of cyclists at measurement points depending on: (a) the ambient temperature, (b). rainfall value [mm], (c). wind speed
Source: Author's research based on [9]

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