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The Bike-Sharing System as an Element of Enhancing Sustainable Mobility—A Case Study based on a City in Poland

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Abstract: The bike-sharing system allows urban residents to rent a bike at one of the rental stations located in the city, use them for their journey, and return them to any other or the same station. In recent years, in many cities around the world, such systems were established to encourage their residents to use bikes as an element of enhancing sustainable mobility and as a good complement to travel made using other modes of transport. The main purpose of this article is to present the results of an analysis of the functioning of the bike-sharing system in Warsaw (Poland). Moreover, the article presents an analysis of the accessibility to individual stations. An important aspect is that the bike-sharing system has been popular among users and that more people use it. Therefore, the city should be provided with a dense network of conveniently located bike-sharing stations. Also, the quality of the bike-sharing system should be an adjustment to the user's expectations. In connection with the above, the article also presents the results of the analysis of factors affecting bike-sharing system usage as well as the level of satisfaction connected with bike-sharing system usage. The results of the analysis showed that there is a strong positive correlation between these variables. The obtained results can be helpful for carrying out activities whose purpose is to increase the bike-sharing system usage as well as to increase the level of satisfaction connected with bike-sharing system usage.

Keywords: bike-sharing system; bike; sustainable mobility; road traffic engineering; road transport

1. Introduction

Cities radically change into smart cities because of the increasing mobility of societies, urban growth, new products, and technological innovations [1–3]. Also, these factors enforce the need to properly shape travellers' behaviour. Currently, in many cities in urban areas, the biggest challenge is to overcome the problem of the prevailing use of private cars [4–7]. Bike-sharing systems are considered to be an effective tool for popularizing alternative ways of traveling, and can be used as an element of enhancing sustainable mobility in cities. Sustainable mobility is the communication behavior of users shaped in this way in the spatial structure and transport, in which the length of the travel route is rationalized, individual motorization does not degrade public transport and non-motorized transport (walking and cycling), and the functioning of the transport system makes it possible to maintain harmony with the environment. Sustainable transport is conducive to improving the city's image and spatial order, as well as creating good quality public space, and also reduces the diversity in the development and quality of life of individual city areas [8]. Contemporary system solutions that connect space and transport planning aim for greater use of the bike as a means of transport. Journeys made by private bikes as well as by bike with the bike-sharing system contribute to significant savings and benefits for both bike users and the natural environment (i.e., no negative impact on the quality of life in the city (no noise and no emissions) protection of monuments and flora; better use of space, both for movement and parking; less degradation of the road network; improvement of the attractiveness of the city center (business, culture, recreation, social life); reduction of congestion and economic losses; increased traffic flow; greater attractiveness of public transport; better access to urban services for the whole society; saving time and money of parents who are exempted from taking their children to school; significant saving of time for cyclists on short and medium distances; no possible necessity owning a second car by the household (budget increase) [9–11]).

However, travel by bike is not able to meet all mobility needs. In large cities and agglomerations, in highly urbanized areas, as well as in the outskirts and rural areas, the car will still be used. In these cases, solutions should be implemented that enable it to be used more effectively. D. Jankowska-Karpa and A. Wnuk in their work [9] proposed changes that may contribute to limiting traffic and at the same time promoting travels by bikes in cities. This may contribute to an increase in the role of travel by bikes in shaping sustainable mobility. These were the following changes:

- At short distances, residents should be encouraged to restrict car use, especially if the journey is short and begins and ends at home (e.g., home-shop-home). In this case, several solutions can be proposed: bike paths, facilities for pedestrians and cyclists to allow free movement, development of convenient infrastructure, e.g., parking spaces, etc.;
- Modernization of streets ensuring the safe and comfortable movement of pedestrians and cyclists at a distance of at least 1 km around each school and promotion of "pedestrian and bicycle buses" for children, which would contribute the reduction of parking lots and traffic flow around schools;
- Many trips by car taken from work during the lunch break. Initiatives should be taken to promote more environmentally friendly means of transport around jobs and planning public spaces in office districts to reduce the number of cars. Employers can support such initiatives, by creating bike parking, free bike rentals, installing lockers at workplaces for storing personal things, etc.;
- The so-called "time policy" can be developed to adapt the offer to the needs of mobility. For example, due to heavy traffic during peak hours, in consultation with employers and authorities, it is possible to synchronize activities and services. This would reduce congestion on some transport network at certain hours. These solutions have already been implemented in some European cities.

The bike-sharing system allows users to rent a bike in one of the automatic stations located in the city, use it during the journey, and return it at the same or any other station. In recent years, systems of this type have been created in many cities around the world to encourage residents to use the bike as an ecological mode of transport or as a part of the journey using other modes of transport. The basic idea of the bike-sharing concept is sustainable transportation. Such systems often operate as part of the city's public transport system. They provide fast and easy access, have different business models, and make use of applied technology like smart cards and/or mobile phones. Table 1 presents the classification of bike-sharing systems currently functioning in the world, due to their operating principles.

The area systems can be divided into four generations. The first generation (bike-sharing on the streets) is the Dutch "Witte Fietsplan" (White Bike Plan), which was announced in 1965 in Amsterdam. Its author was Luud Schimmelpenninck. The purpose of the plan was to provide a maximally simple to use, widely available communication alternative to growing motorization.

Table 1. The classification of bike-sharing systems currently functioning in the world, due to their operating principles. Source: Own research based on data presented in [12,13].

Operating Principles of Bike-Sharing Systems	Bike-Sharing System Description
Point systems	Bike rental and return take place at one or no more than a few points. These points can be automated or operated by staff. In this case, there are both typical commercial rentals and public systems that support cycling mobility by offering free access. A frequent limitation, in this case, is the limited time of renting and returning bikes within a day.
Area systems	Bike rental and return take place at numerous, any points located on a large area (usually in the whole area of dense urban development). In this case, the rental and return procedure is always automated and takes many different forms. This procedure is not usually hourly limited as in the case of the point systems. Due to the greatest potential for cycling mobility, this is the most popular form of the bike-sharing system. Its development can be grouped into subsequent generations.
Point-area systems	Developed based on a close connection between the bike-sharing system and public transport operators, most often based on railway stations. In these systems, bike rental usually takes place at a single point, i.e., at the railway station node. The return can take place at the rental point but also by leaving the bike anywhere in the designated area after completing the appropriate return procedure.
Long-term bike rental systems	These are systems completing the bike-sharing system in the area and mixed type. These systems based on renting bikes for a longer time (from months to years). The fee may be one-off or divided into installments in the amount of part of the costs of buying and utilization a private bike. In systems of this type, users may be required by the regulations, e.g., to use rented bikes for a specified number of journeys to nodes and continue the journey by public transport. These types of systems are a very attractive alternative to other (open) bike-sharing systems, especially in less-populated, peripheral urban areas and in isolated towns with smaller surface and with lower population density. A variant of this type of systems is the long-term rental of electric bikes.

At that time, it began to create huge spatial and environmental problems on the narrow streets of Amsterdam [14,15].

The second generation (bike-sharing systems on bail) started in 1995 in Copenhagen under the name “Bycyclen”. It was the world’s first area-based and automated bike-sharing system consisting of 1000 bikes and 110 bike rental and return stations. The principles of its functioning were a generational breakthrough: the bike could be rented by placing a coin (deposit) in a special slot. When the bike was returned, the coin was recovered. Apart from a returnable deposit, the system was free to use. The system was available 24 hours a day, 7 days a week, from mid-April to November. The bikes were also specially designed—they were very simplified, they had full wheels without spokes and consisted of parts of unusual sizes connected by custom screws (to prevent stealing of bikes for parts). The operating costs of the system were borne by the city of Copenhagen, private companies, e.g., Coca Cola, placing ads on bikes, and to some extent the Danish government. The system operator was a foundation established by the city authorities. The system only allowed movement around the city center. The users were punishable by a fine when they traveled outside the designated area. In this way, the supervision of bikes was improved. The problem was that in this way it prevented the main target group from using the bike-sharing system, i.e., people commuting to the center from neighboring districts. As a result, the system was mainly for tourists. It was a very recognizable and valued symbol of the city’s tourist attractiveness [16,17].

The beginning of the third generation (smart docks) can be regarded the creation of the “Bikeabout” system in the city Portsmouth in England. At first, the system covered classic student rentals. In 1996 the system was expanded and fully automated by using personal magnetic cards. The introduction of full user identification for the first time in the history of the bike-sharing systems contributed to the creation of a system in which no bike has been stolen or damaged. The next step in the development of the third-generation bike-sharing systems was the appearance of systems characterized by a much greater range and number of stations. Additionally, the use of teleinformatics was the most important for supervision and management and introducing relocation to compensate the level of filling the bikes-sharing stations. France has become a significant area of the evolution of the third-generation bike-sharing system. In 1998, the "Velo a la Carte" bike-sharing system was launched in Rennes. It was the first computerized bike-sharing system in the world. This system included 200 bikes, 25 docking stations connected to the central management, three service employees, and a special car for transporting bikes. The system was available to all residents of the city and neighboring metropolitan areas and required a personal magnetic card. Using the vehicle was free within two hours of renting. The business model was based on the public-private partnership of the city authorities with the Clear Channel advertising group [18,19].

The fourth generation (smart bikes): a feature that distinguishes the fourth-generation bike-sharing systems is the departure from the "smart dock" idea that allows rental and return bikes in docking stations, towards "smart bikes". These bikes have built-in identification, rental, closing, and return of bikes. The role of the dock is taken over by a bike, which is equipped with an electric lock and multi-system electronic supervision in real-time (thanks to the GPS (Global Positioning System) and/or GSM (Global System for Mobile Communications) tracking module). The role of the rental terminal in the dock was known from the third generation—partly taken over by the smartphone with Internet access, partly the active rental panel built into the fourth-generation system bike and powered by dynamos (battery, photovoltaic panel). The second characteristic of the fourth generation, presented in the literature [20,21], is much greater integration of the bike-sharing systems with public transport systems and car-sharing systems. It is important to create common channels of remote access to information and services, integrated tariffs and fees for systems operating in the same area, and the implementation of integrated electronic access cards (agglomeration city cards, communication, etc.) [22].

The bike-sharing systems developed around the world in recent years are mainly based on third-generation systems. In Warsaw (Poland), the Warsaw Bike-Sharing System operates as part of Warsaw Public Transport, which is organized by the Municipal Road Management. This system began to operate in 2012 and is a third-generation system. The system's operator and a contractor is NextBike Polska sp. z o.o. According to the ranking prepared by the consumer service ShopAlike.pl [23], Warsaw ranks fourth in Europe in terms of transport-sharing systems. Only Paris, Brussels, and Berlin are more friendly to bike-sharing, scooter-sharing, and car-sharing systems. In Poland, the first bike-sharing system was launched in 2011. Since then, the total number of rentals in all systems in Poland amounted to less than 60 million. Table 2 presents the bike-sharing systems in Poland with the most number of bike rentals in the years 2011–2019.

Table 2. The bike-sharing systems in Poland with the most number of bike rentals in the years 2011–2019. Source own research based on data presented in [24].

Name of the Bike-Sharing System	City in which the System Occurs	System Operation Start Date	The Number of Rentals (millions)
Veturilo—Warsaw Bike-Sharing System	Warsaw	1 August 2012	25.6
Wrocław Bike-Sharing System	Wrocław	8 June 2011	6.3
Łódź Bike-Sharing System	Łódź	30 April 2016	6.0
Poznań Bike-Sharing System	Poznań	15 April 2012	4.5
Lublin Bike-Sharing System	Lublin	19 September 2014	3.4
BiKeR—Białystok Bike-Sharing System	Białystok	31 May 2014	3.1

The main purpose of this article is to present the results of the analysis of the functioning of the bike-sharing system in Warsaw. Moreover, this paper presents an analysis of the accessibility to individual stations, which is made by using isochrones. An important aspect is that the bike-sharing system has been popular among users and that more people use it. Therefore, a dense network of conveniently located bike-sharing stations should be provided in the city. Also, the quality of the bike-sharing system should be an adjustment to the user's expectations. In connection with the above, the article also presents the results of the analysis of factors affecting the bike-sharing system usage, as well as the level of satisfaction connected with the bike-sharing system usage.

2. Literature Review on the Bike-Sharing Systems in the Cities

In Poland, the most important works related to the bike-sharing system belong to the Warsaw Traffic Study 2015 [25–28]. A traffic model was developed for the Warsaw agglomerations as part of the Warsaw Traffic Study. The traffic model was divided into three independent models. The third model is for cycling traffic. The cycling model was prepared according to the principles of the classic four-stage transport model [29–32]. Part of the first stage was determining the generations and absorption of individual origins and destinations of the bike traffic stream, for the identified travel motivations. Then, as part of the second stage, the streams were allocated between individual origins and destinations of the traffic stream. The last stage was the distribution of traffic flow over individual transport roads. This model also mapped the bike-sharing stations Vertuilo which allowed the analysis of travel behaviors of both private bike users and the bike-sharing system Vertuilo users [33]. The research showed that the flow of bike travel is evenly distributed over the Warsaw transport network. The cyclists choose the main communication routes in both the morning and afternoon peak hours. Comparing the morning and afternoon peak hours, an increase in traffic can be observed on selected sections of the network and a decrease in traffic on selected parts of it. In turn, perceived enablers and barriers of the bike-sharing system in Warsaw according to cyclists and non-cyclists presented [34]. The results of a public opinion survey about the bike-sharing system in Warsaw in the first years of its functioning were included in the work of B. Klepackiego and P. Sakowskiego [35].

Due to the fact that the bike-sharing systems became popular in the world only a few decades ago, scientific literature dedicated bike-sharing systems is relatively new. The scientific papers published so far, first of all, relate to the establishment, functioning, analysis, and modeling of bike-sharing systems. The works available in the literature can be divided into several distinct research areas. These are empirical research on the functioning and use of a bike-sharing system—e.g., M.Z. Austwick et al. [36], P. De Maio [37], A. Faghih-Imani et al. [38]—or problems of location and capacity of bike-sharing stations—e.g., I. Frade and A. Ribero [39], J.R Lin and T.H. Yang [40]. Moreover, one can find research works dedicated to modeling and optimizing the repositioning problem—e.g., T. Raviv et al. [41], M. Benchimol et al. [42], D. Chemla et al. [43], T. Raviv and O. Kolka [44]—as well as the functioning of the bike-sharing system and its efficiency in various conditions—e.g., C. Ficker and N. Gast [45], P. Vogel and D.C. Mattfeld [46]—or bike-sharing usage—e.g., C. Morency et al. [47]. An important group of works are works dedicated to bike-sharing system usage prediction—e.g., Y. Li and Y. Zheng [48], Y. Li et al. [49], most often using time series models (e.g., A. Kaltenbrunner et al. [50]), and factors determining the use of the bike-sharing system—e.g., A. Faghih-Imani and N. Eluru [51], T.D. Tran et al., [52], or also the positive influence of the bike-sharing system on people's health and life as well as the natural environment—e.g., B. Alberts et al. [53], R. Jurdak [54], Y. Guo et al. [55].

Also, in the related literature one can find works that show that the location of stations in densely populated places and places of concentration of workplaces increases the number of rentals (e.g., R. Rixey [56]). A similar pattern can occur in the situation of stations near to schools, universities, places of concentration of services, and places of entertainment such as restaurants, bars, cinemas, and shops (e.g., A. Faghih-Imani et al. [57]).

In turn, F. Gonzalez et al. [58], R. Nair et al. [59], A. Faghih-Imani et al. [60] analyzed the influence of the occurrence of bike-sharing stations at public transport systems such as bus stations, train stations, metro stations, and bus stops. The results of these analyses show that the location of the bike-sharing stations at public transport systems also increases the bike-sharing stations usage.

Analyzing articles on bike-sharing systems, they indicate that the analyses contained in these works are most often based on data obtained from surveying bike-sharing system users or managers—e.g., E. Fishman et al. [61], Y. Tang et al. [62], S. Kaplan et al. [63], or surveying the bike-sharing system operator—e.g., T. Raviv et al. [41], P. Świerk [64], A. Kurek [65], or online sources of usage at stations—e.g., P. Jimenez et al. [66], R. Hampshire [67], X. Wang et al. [68].

In cities where bike-sharing systems have been operating for a long time, research has been conducted to obtain information from bike-sharing system users about the quality of system functioning. These data can be used by decision-makers to improve the offer and functioning of the bike-sharing system so that it meets users' expectations as much as possible. Studies on factors affecting on bike-sharing system usage as well as the level of satisfaction connected with bike-sharing system usage have been conducted so far, e.g., Y. Guo et al. [69]. The purpose of this research was to understand the factors affecting the low bike-sharing system usage in Ningbo (China). Based on their research a few conclusions connected with planning, engineering, and public advocacy were discussed in order to increase the bike-sharing system usage in the mentioned city. A similar survey was performed by L. Caggiani et al. [70]. They proposed an optimization model able to determine how to employ a given budget to enhancing a bike-sharing system, maximizing global user satisfaction. In turn, C. Etienne and O. Latifa proposed a model for the bike-sharing system in Paris [71], which identifies the latent factors that shape the geography of trips, and the results offer insights into the relationships between station neighborhood type and the generated mobility patterns. G. Manzi and G. Saibene [72] analyzed the level of satisfaction connected with bike-sharing service usage through surveys carried out in Milan.

In the literature, there are many different scientific papers about the attempt to determine the level of satisfaction with the bike-sharing system usage, which were conducted in various cities around the world, e.g., F. Xin et al. [73] conducted this type of research for Shanghai, D. Efthymiou et al. [74] for Greece, J. Shi et al. [75] for China. Analyzing these works, it can be stated that the approaches to conducting research were very different in terms of the method of obtaining data for analysis, the number of research samples, the manner of conducting analyses, as well as the conclusions obtained.

3. Veturilo—Warsaw Bike-Sharing System

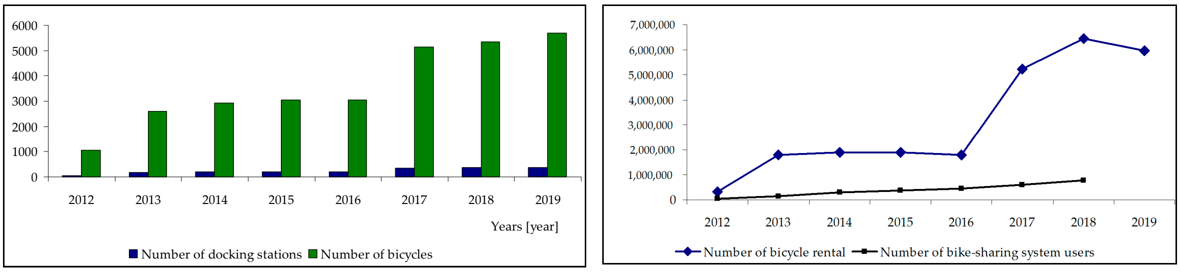
The operator and contractor of the Warsaw Bike-Sharing System (Veturilo) is the company Nextbike Polska z o.o., which operates under the license of Nextbike GmbH [76]. The Nextbike system is popular in the world. Currently, it operates in over 200 cities in the world, in 16 countries on 4 continents. In Poland, Nextbike operates in dozens of cities. According to the data from the system operator, in 2019 in Poland had access for over 8 million people to the bike-sharing system. In Warsaw, it operates in 17 districts (no system in the Wesoła district) and consists of 377 stations (which 335 are city stations and 42 are sponsor stations, i.e., financed by private parties) (see Figure 1).

Figure 1 shows statistical data characterizing the number of stations, bikes, users and rentals in the Veturilo system in Warsaw in 2012–2019.

Figure 2 shows the schematic location of the Veturilo bike-sharing stations in Warsaw. At the stations are 5337 bikes, which are available in the following types [78]:

- standard;
- children 4+ (dedicated to children over 4 years and 110 cm tall, these bikes have 18-inch wheels);
- children 6+ (designed for children over 6 years and 120 cm tall, these bikes have 20-inch wheels);
- tandem (designed for two people who sit one behind the other. The tandem has one frame and two wheels, while each person has its own steering wheel, saddle and pedals. The maximum load of a tandem is 227 kg);

- electric (equipped with an electric motor, which covers up to 82% of the effort associated with driving. The battery allows travel from 60 to 130 km. Electric support works at speeds up to 25 km/h);
- bike with cardan shaft (it is not equipped with a chain but with a set of joints that drive the bike. This type of bike is definitely less emergency than a standard bike with a chain).



(a) (b)

Figure 1. Characteristics of the Veturilo system in Warsaw in 2012–2019; (**a**) number of docking stations and bikes; (**b**) number of bike-sharing systems users and bikes rental. Source: Own research based on data presented in [76–79].

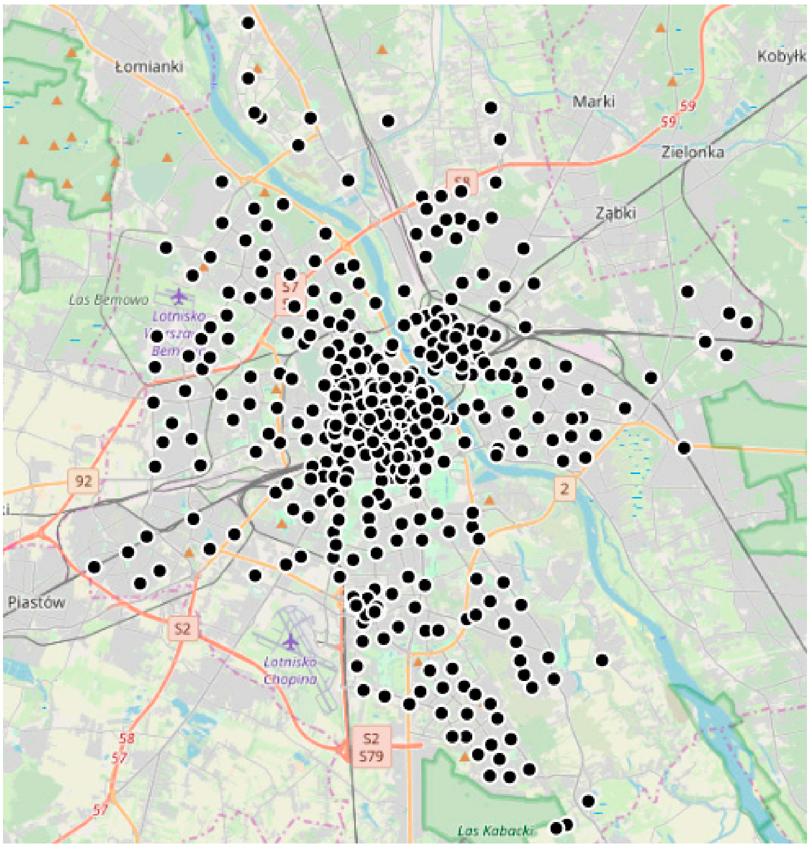


Figure 2. Locations of the Veturilo system stations in Warsaw. Source: Own research based on data presented in [64,76,78,79].

The children's bikes are available at selected stations. The children may use these bikes only in the care of an adult. In turn, the tandem bikes increase the attractiveness of the system in terms of recreation journey and give the possibility of a joint journey of people with the same origin and destination. In addition, a tandem is a great solution, e.g., for people with disabilities who can use this mode of transport only in this form. In Warsaw, the electric bike has been available for rent since August 2017 at one of the eleven selected stations. The electric bikes have a separate price list. Renting an electric bike is more expensive than renting other types of bikes.

To start using the Veturilo system, it is necessary to register as a user in the system. This can be done in four ways, i.e., by completing the registration form on the website www.veturilo.waw.pl, using the terminal located at each station, using the Veturilo mobile application, or by contacting the 24-hour call center.

Then, the newly created account must be topped up with an initial payment of 10 PLN or a credit card added as a payment method. Account activation is done by clicking on the verification link, which is sent to the e-mail address provided in the registration. After registering, the user receives an SMS and an e-mail containing the PIN code. The PIN code together with the user's phone number are identifiers in the Veturilo system.

To rent a bike, the "Rental" button must be selected at the bike-sharing station terminal and the instructions that will be shown on the display must be followed. After completing the rental procedure, the bike is automatically released from the electric lock. The user can also rent a bike via the Veturilo mobile application or by contacting the call center. If the bike is secured with a combination lock, the code displayed on the terminal should be entered. This code is also provided in the mobile application throughout the bike rental time. The return of the bike is done by connecting the bike to the electric lock. This is confirmed by a sound signal and a green diode. On the terminal or in the mobile application the user should check that the return has been made correctly. When all electric locks are occupied at the station, the user can secure the bike with a combination lock. Table 3 presents the price list for renting a standard, children, tandem, or electric bike from the bike-sharing system in Warsaw. The price list also contains information about the number of fines for theft, loss, or destruction of bikes (Table 4).

Table 3. The price list for renting a standard, children, tandem, or electric bike from the bike-sharing system in Warsaw system (assuming exchange rate 1 €= 4.26 PLN). Source: Own research based on data presented in [79].

Action/Rental Time	Price List for Renting a Standard, Child, or Tandem Bike	Price List for Renting an Electric Bike
During registration to the system	10 PLN (2.35 €)	10 PLN (2.35 €)
The first 20 min	0 PLN (0.00 €)	0 PLN (0.00 €)
From 21 to 60 min	1 PLN (0.23 €)	6 PLN (1.41 €)
Second hour	3 PLN (0.70 €)	14 PLN (3.27 €)
Third hour	5 PLN (1.17 €)	14 PLN (3.27 €)
The fourth and subsequent hours	7 PLN (1.64 €)	14 PLN (3.27 €)
Over 12 h of using the bike	200 PLN (46.95 €)	300 PLN (70.42 €)

Table 4. Information about the fines for theft, loss, or destruction of bikes from the bike-sharing system in Warsaw. Source: Own research based on data presented in [79].

Types of Bicycles	The Price List
Standard bike	2000 PLN (469.48 €)
Tandem bike	7000 PLN (1643.19 €)
Children's bike	1900 PLN (446.01 €)
Electric bike	12000 PLN (2816.90 €)

4. Research Methodology

The main purpose of this work was:

- analysis of the functioning of the bike-sharing system in Warsaw;
- analysis of access to stations;
- analysis of factors affecting bike-sharing system usage as well as the level of satisfaction connected with bike-sharing system usage;
- surveying preferences among users of the bike-sharing systems.

Data were obtained from the operator Veturilo Nextbike to analyze the functioning of the bike-sharing system in Warsaw. These data covered the functioning of the system in 2018, i.e., from March to November 2018. In order, QGIS (Quantum Geographic Information System)and Open Street Maps were used to perform the availability analysis. In turn, a survey questionnaire was used for the analysis of factors affecting the bike-sharing system usage as well as the level of satisfaction connected with the bike-sharing system. This type of research has been used commonly in transport engineering. The form and content of the survey questionnaire was developed based on a broad review of the literature. The reliability of the questionnaire and its internal consistency were checked using the Cronbach's alpha coefficient (α) ([80–85]). The value of this factor was $\alpha = 0.743$, which confirmed that the constructed questionnaire was a tool that could be used to measure the bike-sharing system usage as well as the level of satisfaction connected with bike-sharing usage. The final form of the questionnaire was discussed, assessed, and corrected by an expert team (four independent experts assessed its layout, readability, style, and transparency of questions). To assess respondents' answers a five-point Likert scale was used—from 1 (bad) to 5 (excellent) [86–88]. The average rating for the questionnaire was 4.5, which confirmed the satisfactory validity of the questionnaire.

The data obtained from the questionnaire were analyzed. The bivariate ordered probit modeling technique was used to identify the significant factors affecting bike-sharing usage and users' level of satisfaction. This modeling technique took into account the correlation between independent variables. As a result, a conceptual model was obtained consisting of factors related to the bike-sharing system usage and users' level of satisfaction. The questionnaire consisted of several parts. In the survey, respondents answered questions about:

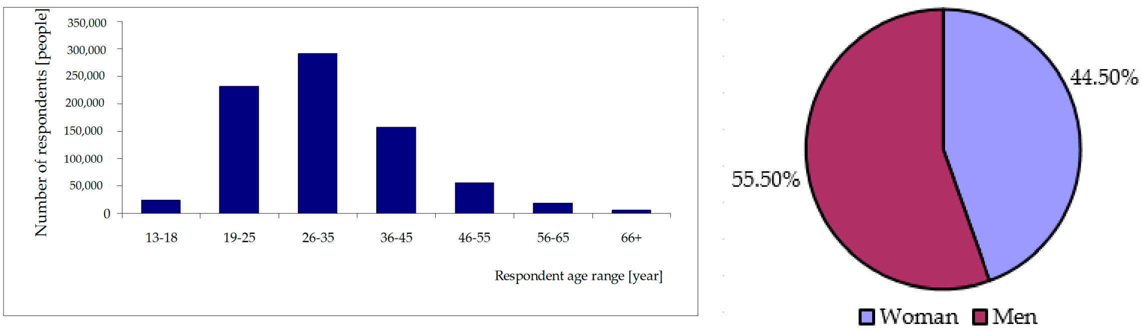
- data that characterized the respondent's profile: age, gender, occupation, education level, monthly income, information about having in the household a bike, e-bike, car (and number of them), etc.;
- use of the bike-sharing system (the answers used a three-point Likert scale, where: 1—rarely, 2—medium, 3—often);
- the level of satisfaction of bike-sharing system usage (the answers used a three-point Likert scale, where: 1—lack of satisfaction, 2—average satisfaction, 3—fully satisfaction);
- travel patterns, including such information as: trip purpose (during weekdays and weekends), trip mode, travel time, bike-sharing station availability within 500 m near home and workplace/university, bus stops/tram stops/railway station availability within 500 m near home and workplace/university;
- perception of the bike-sharing system, including such information as: familiarity with the bike-sharing system, satisfaction with bike-sharing fees, easiness to check-in and check-out, saving travel costs by bike-sharing, etc.

The surveys were conducted among users of the bike-sharing system in Warsaw, around bike-sharing stations, from 2016 to 2019. All persons participating in the survey had previously agreed to participate in the survey. The survey was conducted on weekdays and weekends to obtain a large size and varied answers of the respondents. The random sampling technique was used in order to select the bike-sharing system users. People over 18 years took part in the survey. A total of 1600 questionnaires were collected. The questionnaires were examined in terms of data correctness and completeness (e.g., the questionnaires were rejected in which: respondents indicated that they were using the system for the first time; respondents said that they contained incomplete information; respondents could not indicate their assessment, e.g., "I do not know", "I have no opinion of my own", "I have not such as situation"). A total of 1584 survey questionnaires remained in the database as a result of the selection. These data were the basis for analysis.

5. Analysis of the Functioning of Warsaw Bike-Sharing System in 2018

5.1. The Characteristics of System Users and the Structure of Using Bike-Sharing Stations

According to [89], the number of users of the bike-sharing system in Warsaw was 785,000. Figure 3a shows the age structure of users. The obtained data indicated that most users are between 25 and 35 years old (which is 37.13% of the total, i.e., about 291,500 people). Another numerous age group of people using Veturilo is the range from 19 to 25 years old. This range is 29.47% of all users (i.e., around 231,500 people). The least numerous group of the bike-sharing system users are elderly people over the age of 66 (6240 users). The average age of people using the system in 2018 was 32 years.

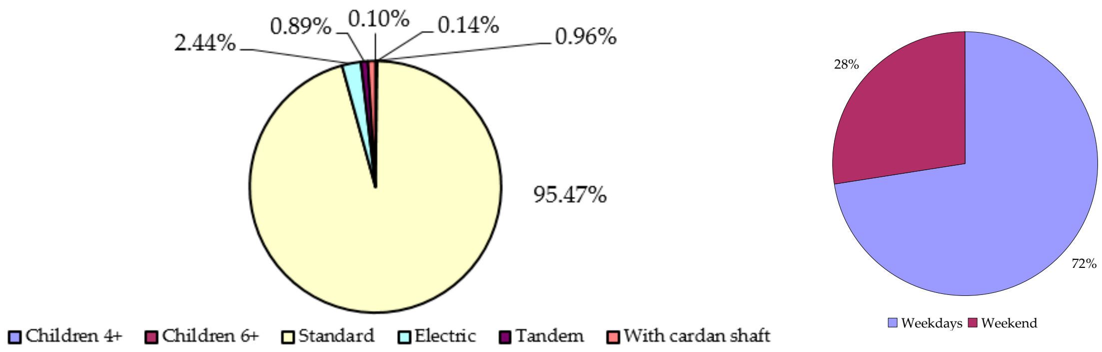


(a) (b)

Figure 3. (**a**) Age structure; (**b**) sex structure of people using Veturilo in Warsaw in 2018. Source: Own research based on data presented in [77].

Figure 3b shows the gender structure of the bike-sharing system users. The data indicate that slightly more men (55.5%) than women (44.5%) use the bike-sharing system in Warsaw.

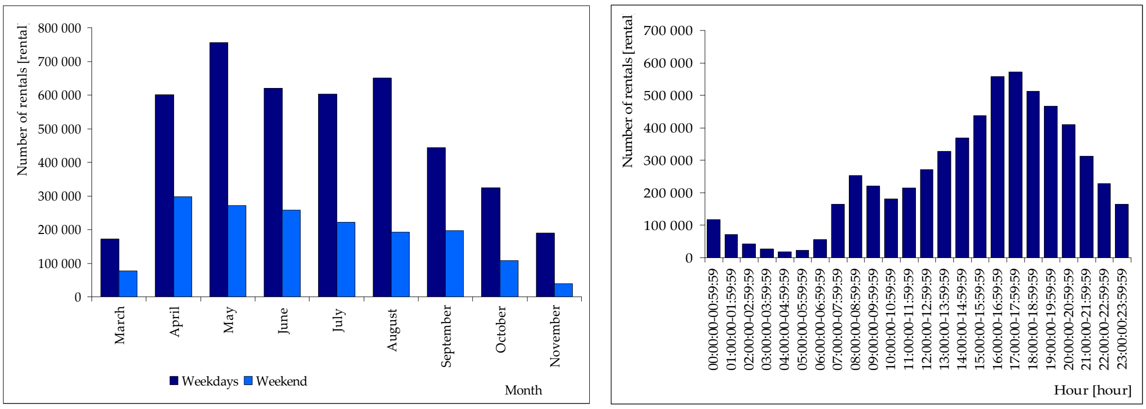
The obtained data also made it possible to state that in 2018 standard bikes were the most often rented (95.5%) and the least often rented were bikes for children 4+ (which was 0.1% of all rentals—i.e., 5821 rentals)—see Figure 4a. In turn, Figure 4b presents data on bike rentals on weekdays and weekends. A total of 72% of all rentals took place on weekdays. In the analyzed period, this was the majority of all rentals. On weekdays, the bikes were rented on average 22,150 times a day. Weekend rentals were 28% of all rentals.



(**a**) (**b**)

Figure 4. The number of bike rentals from the Veturilo system in Warsaw in 2018 (**a**) considering types of bikes; (**b**) on weekdays and weekends. Source: Own research based on data presented in [77].

Moreover, Figure 5a shows the number of bike rentals from March to November on weekdays and weekends. The most rentals were in May. In April, June, July, and August, the number of rentals were at a similar level. From August to November a decrease could be observed in the number of Veturilo bike rentals. The least rentals were in March and November. It is possible that this was caused by weather conditions in Poland at this time of the year. The most rentals on weekends took place in April. The number of rentals decreased in each subsequent month. The least rentals on weekends were in March and November, as on weekdays.



(**a**) (**b**)

Figure 5. The number of bike rentals from the Veturilo system in Warsaw in 2018; (**a**) from March to November on weekdays and weekends; (**b**) at particular hours of the day. Source: Own research based on data presented in [77].

Figure 5b shows the number of bike rentals at particular hours of the day. The largest number of rentals were between 17:00 and 17:59 and between 16:00 and 16:59. In the following hours, the number of rentals decreased, up to hours between 04:00 and 04:59, when the number of rentals was the lowest. Between 07:00 and 11:59, the number of rentals was around 200,000 rentals per hour. In the afternoon this number increased with each subsequent hour until it was maximum value between 17:00 and 17:59.

Figures 6 and 7 present the number of bike rentals and returns on particular stations. The most bikes were rented from the stations Arkadia, Plac Wileński, Metro Centrum Nauki Kopernik, and Al. Niepodległości-Batorego, whereas the least were from the stations Komandosów-Niedziałkowskiego, Paderewskiego-Dziewanowska, Frontowa—Czerwonych Beretów, PKN Orlen-Wydawnicza, and Niepołomicka-Chełmżyńska.

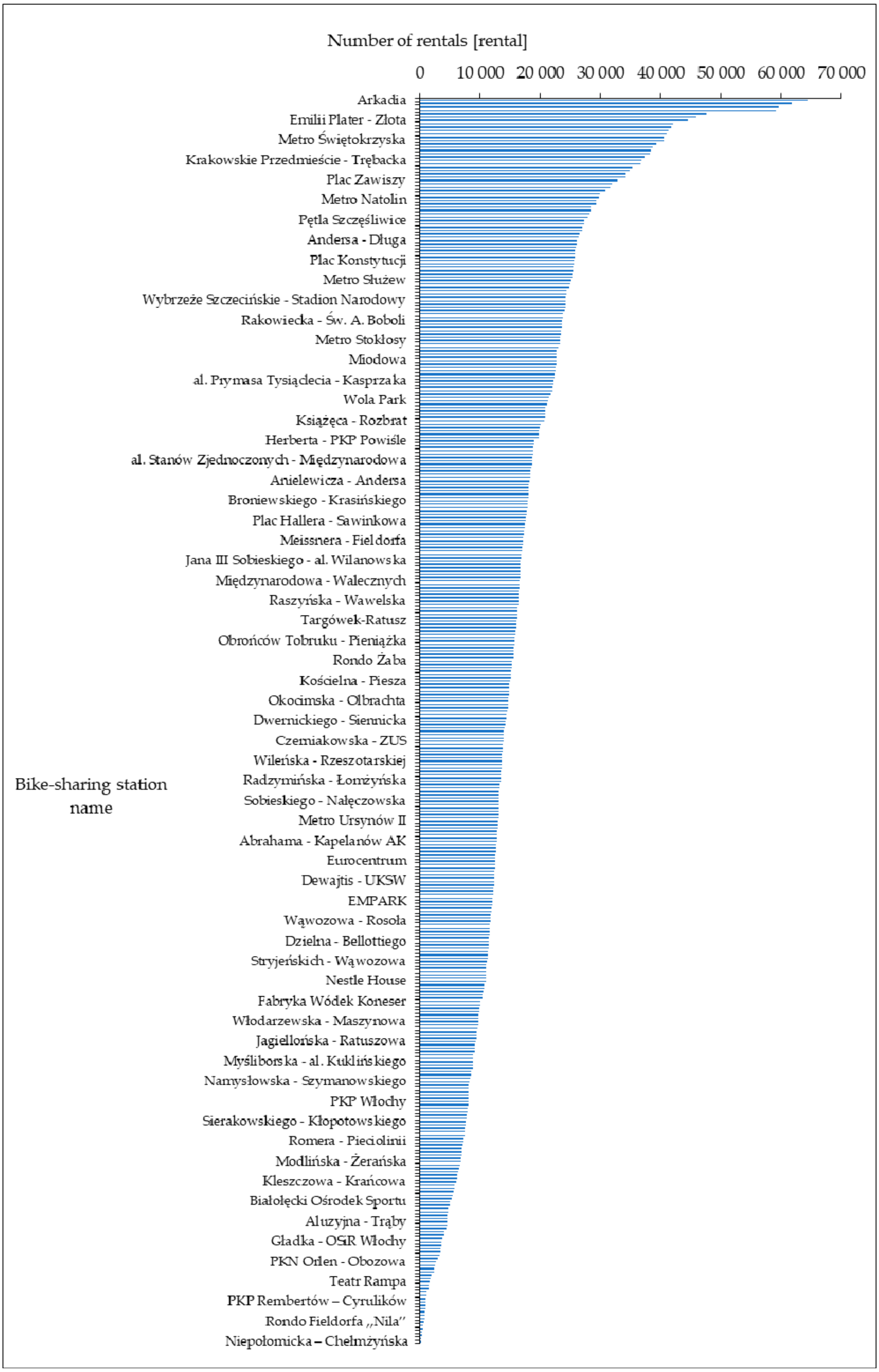


Figure 6. The number of bike rentals from individual stations in the Veturilo system in Warsaw in 2018. Source: Own research based on data presented in [77].

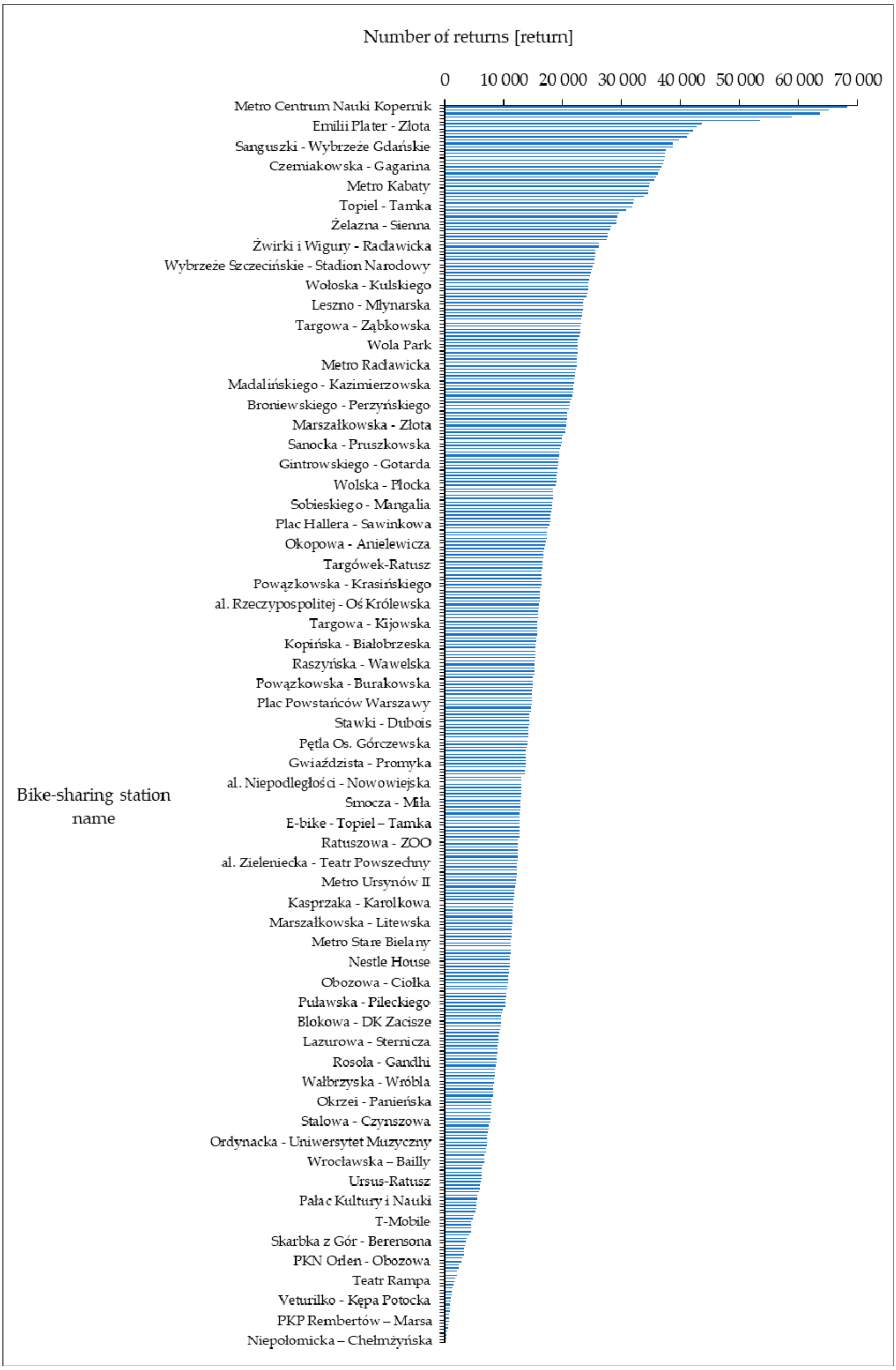


Figure 7. The number of bike returns to individual stations in the Veturilo system in Warsaw in 2018. Source: Own research based on data presented in [77].

In the case of bike returns, the most bikes were returned to the stations Arkadia, Plac Wileński, Metro Centrum Nauki Kopernik, and Al. Niepodległości-Batorego. In turn, the least returns were to the stations Komandosów-Niedziałkowskiego, PKN Orlen-Wersalska, Frontowa-Czerwonych Beretów, PKN Orlen-Wydawnicza, and Niepołomicka-Chełmżyńska.

The average number of rentals and returns from and to each station was around 16,000 rentals/stations in 2018.

5.2. The Bike-Sharing Stations in the Criterion of Popularity among Users

Figure 8 shows the bike-sharing stations which were the most and the least popular among system users in 2018. The most popular stations included: Metro Centrum Nauki Kopernik, Arkadia, Plac Wileński, Al. Niepodległości-Batorego, Port Czerniakowski, Rondo Jazdy Polskiej, Emilii Plater-Złota, Plac Unii Lubelskiej, Stefana Banacha-UW, Metro Nowy Świat-Uniwersytet, Metro Świętokrzyska, Rondo ONZ, Sanguszki-Wybrzeże Gdańskie, Al. Jerozolimskie-Emilii Plater, Al. Jana Pawła II- Plac Mirowski, Metro Dworzec Gdański, Krakowskie Przedmieście-Trębacka, Al. Jana Pawła II-Grzybowska, Czerniakowska-Gagarina, Plac na Rozdrożu, Rondo Waszyngtona-Stadion Narodowy, Al. Jana Pawła II-Al. Solidarności, Belwederska-Gagarina, Grójecka-Bitwy Warszawskiej 1920 roku, Metro Kabaty, Rondo Wiatraczna, Sobieskiego-Chełmska, and Metro Imielin. In turn, the least popular stations included: Niepołomicka-Chełmżyńska, PKN Orlen-Wydawnicza, PKN Orlen-Wersalska, Frontowa-Czerwonych Beretów, Paderewskiego-Dziewanowska, Komandosów-Niedziałkowskiego, Rondo Fieldorfa "Nila", PKN Orlen-Migdałowa, CH Marywilska 44, PKP Rembertów-Marsa, and PKN Orlen-Powsińska.

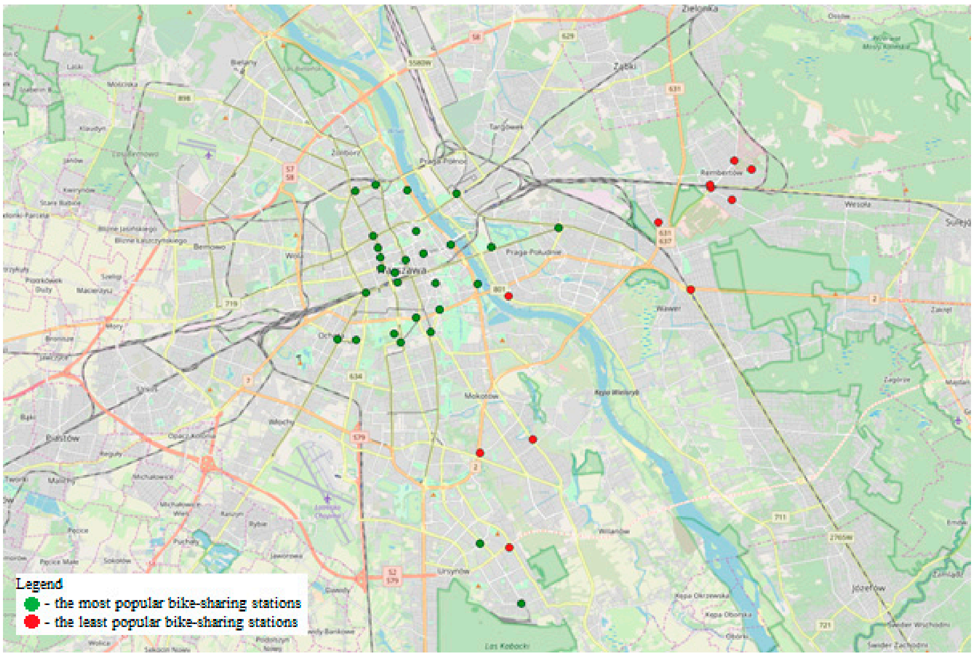


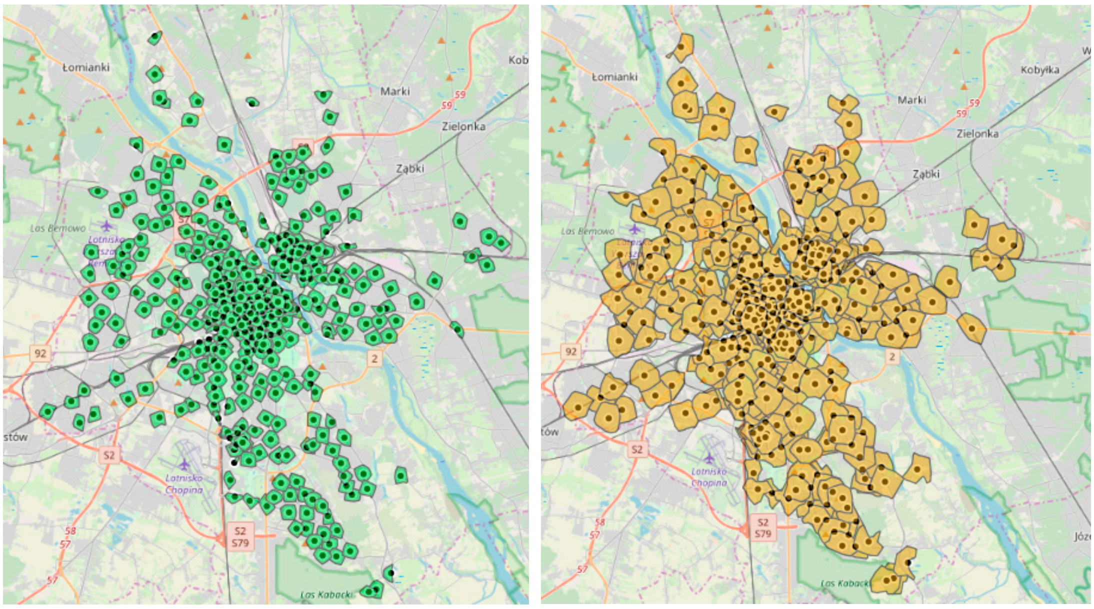
Figure 8. The bike-sharing stations; (**green**) the most popular among users; (**red**) the least popular among users in 2018. Source: Own research based on data presented in [77].

As can be seen in Figure 8, in the area of two districts of Warsaw, the bike-sharing stations which were the least popular among users are located near the bike-sharing stations which were the most popular among users. In the case of bike-sharing stations located in the Ursynów district, the reason may be that both the bike-sharing stations which were the most popular among users are located near the metro line stations. However, the bike-sharing station which was the least popular among users is located at the Orlen petrol station. Another district in which this is the case is Praga Południe. The bike-sharing station which was the least popular among users, also as in the previous case, is located at the Orlen petrol station. However, the bike-sharing stations which were the most popular among users located in the same district and on the same side of the Vistula River are located near public transport stops, which are served by a large number of bus and tram lines. The above analyses indicate that probably in the case of the most popular among users bike-sharing stations which are located at metro line stations and public transport stops, users are people who use bike-sharing stations as a continuation of their journey.

5.3. Pedestrian Accessibility to the Bike-Sharing Stations

The quality of bike-sharing stations functioning depends on, e.g., time of arrival at the nearest station, the accessible bikes at the station, the technical condition of the bikes, prices for using the bike as well as cleanliness and equipment of the bike, weather conditions. ArcGIS (Geographic Information Systems) technologies with the Network Analyst extension were used to analyze pedestrian accessibility to the bike-sharing stations in Warsaw. It allows realizing various network analyses, e.g., modeling pedestrian or car movements using existing roads. The areas were designated from which it is possible to get to the bike-sharing station at the assumed travel time (time distance of 5 and 10 min) only on foot. Then, the obtained information was compared with data on the location of residential buildings in Warsaw. This was transformed into indicators showing the spatial extent of accessibility areas and the number of inhabitants for which access to particular stations is the best. This made it possible to make a general assessment of the location of stations in terms of the time of arrival using different methods.

The necessary information was used to model the accessibility of the bike-sharing stations (i.e., vector data illustrating the location of single-family and multi-family buildings accessible in the Topographic Objects Database, vector data regarding the streets in Warsaw, data illustrating the location of bike-sharing stations, obtained as a result of a query of the information in the OpenStreetMap [90] database). The obtained data about the bike-sharing stations were checked and corrected using maps accessible on Google Maps [91]. Then, the information was converted to GTFS (General Transit Feed Specification) format by exporting to text. Figure 9 presents the final results of the analysis of pedestrian access to individual bike-sharing stations in Warsaw in the time category (time distance of 5 and 10 min). This accessibility is marked on the map with isochrones.



(**a**) (**b**)

Figure 9. Pedestrian access to the bike-sharing station in Warsaw; (**a**) on the assumption of an average travel time of 5 min to the station; (**b**) on the assumption of an average travel time of 10 min to the station. Source: Own research based on data presented in [77].

On the basis of data presented on Figure 9, it can be stated that pedestrian accessibility to bike-sharing stations is very good, assuming travel times to the station of 5 and 10 min for stations located in the city center and some districts distant from the center, e.g., Wilanów, Bródno, and Natolin. Pedestrian accessibility deteriorates in districts away from the city center, close to the administrative borders of Warsaw, which is due to the small number of bike-sharing stations in these districts.

6. Analysis of Factors Determining the Bike-Sharing System Usage as Well as the Level of Satisfaction Connected with Bike-Sharing Usage

6.1. Features of Respondents, Household of Respondents and Travel Patterns

Table 5 presents the results of the cross-tabulation of the respondents in the field bike-sharing system usage and level of satisfaction connected with bike sharing-system usage. The bike-sharing system usage was defined as a typical ordinal variable according to three groups: (1) rarely—one–two days per week, (2) average—three–four days per week, and (3) often—five–seven days per week. In turn, the level of satisfaction was also defined as a typical ordinal variable according to three groups: (1) lack of, (2) average, (3) fully.

Table 5. Respondents' bike-sharing system usage and level of satisfaction connected with using the bike-sharing system.

Usage	Satisfaction			Total
	Fully	Average	Lack of	
Often	229	102	7	338 (21.34%)
Medium	385	212	11	608 (38.38%)
Rarely	325	286	27	638 (40.28%)
Total	939 (59.28%)	600 (37.88%)	45 (2.84%)	1584 (100%)

Respondents who often used the bike-sharing system were 21.34% of the total, while 38.38% of all respondents were people who used the bike-sharing system an average amount. This value is comparable to those who rarely use the bike-sharing system (40.28%). The results confirmed that the bike-sharing system is not used often by users (most of the answers were "average" and "rarely").

In the case of the level of satisfaction connected with the bike-sharing system usage, it can be stated that the majority of respondents were fully satisfied with the bike-sharing system and its functions and they assessed the bike-sharing system at a very high level (59.28%). A total of 37.88% of all respondents assessed the level of satisfaction connected with the bike-sharing usage at an average level without indicating the disadvantages or advantages of the system. Meanwhile, 2.84% of all respondents expressed dissatisfaction with the system. The conclusion is that most of all respondents positively assessed the functioning of the bike-sharing system.

The questions included in the survey allowed the selection of many explanatory variables (independent, endogenous). Then, these variables were used to determine their impact (or no impact) on bike-sharing system usage and users' level of satisfaction connected with using the bike-sharing system. Tables 6–9 present information about the characteristics of households of respondents, travel patterns, and information on the environment in which respondents live (bike-sharing station availability close to home/workplace/school/university and bus station/tram stop/railway station availability near home/workplace/school/university (within 500 m)).

Table 6. Characteristics of respondents.

Variable	Characteristics	Symbol	Frequency	Percentage (%)
Gender	Male	1	945	59.66
	Female	0	639	40.34
Age group	Young (18–29)	2	682	43.06
	Middle aged (30–45)	1	802	50.63
	Old (50–70)	0	100	6.31
Level of education	Primary	3	12	0.76
	Secondary	2	472	29.80
	Bachelor/Engineer	1	693	43.75
	Higher	0	407	25.69
Occupation	Student	6	529	33.40
	Employee in company or enterprise	5	493	31.12
	Self-employed	4	172	10.86
	Military	3	12	0.76
	Freelance	2	258	16.29
	Retired	1	81	5.11
	Others	0	39	2.46
Monthly income (Gross) (PLN)	>5000	3	251	15.85
	4000–5000	2	532	33.59
	3000–4000	1	633	39.96
	<3000 *	0	168	10.61

* In 2019, the minimum wage in Poland was PLN 2250 gross.

Table 7. Characteristics of respondents' households.

Variable	Characteristics	Symbol	Frequency	Percentage (%)
Owning a car	Yes	1	1359	85.80
	No	0	225	14.20
Owning bicycle/e-bike in house	Yes	1	112	7.07
	No	0	1472	92.93

Table 8. Characteristics of travel patterns.

Variable	Characteristics	Symbol	Frequency	Percentage (%)
Type of means of transport used for travel	Walking	5	108	6.82
	Bicycle	4	257	16.22
	E-bike/motorcycle/Electric scooter	3	21	1.33
	Public bus or rail transit	2	567	35.80
	Public transport and bike	1	113	7.13
	Passenger car	0	518	32.70
Travel time [min]	<30	2	479	30.24
	30–60	1	733	46.28
	>60	0	372	23.48
Trip purpose during weekdays	Work	5	429	27.08
	School/University	4	684	43.18
	Shopping	3	57	3.60
	Spending free time	2	278	17.55
	Visiting friends	1	102	6.44
	Other	0	34	2.15
Trip purpose during weekends	Work	5	387	24.43
	School/University	4	437	27.59
	Shopping	3	162	10.23
	Spending free time	2	327	20.64
	Visiting friends	1	257	16.22
	Other	0	14	0.88

Table 9. Characteristics of the environment in which the respondents operate (i.e., bike-sharing station availability close to home/workplace/school/university and bus station/tram stop/railway station availability near home/workplace/school/university (within 500 m)).

Variable	Characteristics	Symbol	Frequency	Percentage (%)
Bike-sharing station availability close to home/workplace/school/university (within 500m)	Yes	1	484	30.56
	No	0	1100	69.44
Bus station/tram stop/railway station availability near home/workplace/school/university (within 500m)	Yes	1	1208	76.26
	No	0	376	23.74

Based on the data contained in Table 6, it can be concluded that the group of respondents was diverse due to different characteristics such as age, gender, level of education, occupation, and monthly income. On the other hand, analysis of the data contained in Table 7 shows that the majority of respondents had their own car and did not have a bike in the household.

In turn, travel patterns included in Table 8 indicated that a significant proportion of respondents were public transport users or people using a passenger car in their daily travels. These were the respondents whose travel time usually ranged from 30 to 60 min.

The data in Table 9 indicate the positive characteristics of the environment in which the respondents operate. The majority of respondents indicated that within 500 m from their place of residence, workplace, school, university, they could find a bike-sharing station and bus station (or tram stop or railway station). The above indicates the positive features of public transport in Warsaw.

Table 10 presents the potential independent variables affecting the perception of the bike-sharing system. These are the variables:

- knowledge of the rules of using bike-sharing systems, i.e., rules of use, fees for use, rules of technical maintenance when renting and returning a bike;
- acceptance of the fee for using the bike-sharing system;
- the existence of incentives for travel in the city using an ecological form of transport like bikes, e-bikes, public transport, walking;
- the ability to reduce travel costs by using the bike-sharing system;
- extension of travel time (loss of time) by using the bike-sharing system;
- the ability to adapt the travel route to user needs thanks to the use of the bike-sharing system;
- knowledge about the bike-sharing system obtained from extensive social campaigns, e.g., explaining to society the advantages and disadvantages of using the system, transport policy, potential benefits;
- easy to use the bike-sharing system in terms of registering in the system, paying fees, using a credit card;
- easy to use the bike-sharing system during bike rental—for the bike rental process up to 5 minutes (for the process of renting for more than 5 minutes, it was assumed that technical service is not easy);
- easy to use the bike-sharing system during bike return for the bike return process up to 5 minutes (for the process of returning for more than 5 minutes, it was assumed that technical maintenance is not easy).

Table 10. Potential variables affecting the perception of the bike-sharing system.

Variable	Characteristics	Symbol	Frequency	Percentage (%)
Knowledge of the principles of using bike-sharing systems (i.e., rules of use, fees for use, rules of maintenance when renting and returning a bike)	Yes	1	1557	98.30
	No	0	27	1.70
The existence of incentives for travel in the city using an ecological form of transport (like bikes, e-bikes, public transport, walking)	Yes	1	251	15.85
	No	0	1333	84.15
Acceptance of fees for using a bike-sharing system	Yes	1	749	47.29
	No	0	835	52.71
Extending travel time (loss of time) by using a bike-sharing system	Yes	1	301	19.00
	No	0	1283	81.00
The possibility of reducing travel costs by using a bike-sharing system	Yes	1	489	30.87
	No	0	1095	69.13
Knowledge of the bike-sharing system obtained from extensive social campaigns (regarding, among others, explaining to the public the advantages and disadvantages of using the system, transport policy, potential benefits)	Yes	1	61	3.85
	No	0	1523	96.15
The option of adapting the travel route to your needs thanks to the use of a bike-sharing system	Yes	1	692	43.69
	No	0	892	56.31
Easy to use of the bike-sharing system in terms of registration in the system, payment of fees, use of a credit card	Yes	1	990	62.50
	No	0	594	37.50
Easy to use the bike-sharing system during the bike rental process up to 5 minutes	Yes	1	1428	90.15
	No	0	156	9.85
Easy to use the bike-sharing system during bike return measured by the time of the bike return process up to 5 minutes	Yes	1	1390	87.75
	No	0	194	12.25

6.2. *Bivariate Ordered Probit Model Formulation*

A bivariate ordered probit model (BOP) is a hierarchical structure of two equations that can be used to model the simultaneous relationship of two variables. BOP makes it posisble to solve potential endogenous problems, e.g., the correlation between the explained variable and the explanatory variable in the model [92]. The bivariate ordered probit model has been used many times in modeling the variability of the phenomenon occurring in road transport [93–96].

This study aimed to identify factors that simultaneously determine the bike-sharing system usage as well as the level of satisfaction connected with bike-sharing system usage. Discrete modeling techniques were used as the dependent variables consist of category variables. At the beginning, for each observation ordinal data were defined [94–98]:

$$\begin{cases} y^*_{i,1} = \beta_1 X_{i,1} + e_{i,1},\ y_{i,1} = j\ if\ \lambda_{j-1} < y^*_{i,1} < \lambda_j,\ \ j = 0,\ldots,J \\ y^*_{i,2} = \beta_2 X_{i,2} + e_{i,2},\ y_{i,2} = k\ if\ \gamma_{k-1} < y^*_{i,2} < \gamma_k,\ \ k = 0,\ldots,K \end{cases}, \tag{1}$$

where y is the integer ordering, $y^*_{i,1}$, $y^*_{i,2}$ are the hidden dependent variables,$y_{i,1}$, $y_{i,2}$ are the bike-sharing system usage results according to the ordinal scale (1, 2, 3) and according to the ordinal scale for level of satisfaction connected with bike-sharing system usage (1, 2, 3), $X_{i,1}$, $X_{i,2}$ are vectors consisting of explanatory variables in two models, β_1, β_2 are the parameter vectors for estimation, $e_{i,1}$, $e_{i,2}$ are the random error for the models with normal distribution with mean = 0 and variance = 1, i is individual observations, j is bike-sharing system usage, k is the level of satisfaction connected with bike sharing usage, λ, γ are the estimated threshold parameters, which define $y_{i,1}$ and $y_{i,2}$.

The cross-equation of correlated errors in the BOP model can be written as:

$$\begin{bmatrix} e_{i,1} \\ e_{i,2} \end{bmatrix} \approx N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & r \\ r & 1 \end{bmatrix} \right), \tag{2}$$

where r is the correlation coefficient between $e_{i,1}$ and $e_{i,2}$.

If random errors have the bivariate normal distribution, a common probability for $y_{i,1} = j$ and $y_{i,2} = k$ can be written as:

$$\begin{aligned} &P\left(y_{i,1} = j,\, y_{i,2} = k \middle| X_{i,1}, X_{i,2}\right) = \Pr\left(\lambda_{j-1} < y^*_{i,1} < \lambda_j;\, \gamma_{k-1} < y^*_{i,2} < \gamma_k\right) \\ &= \Pr\left(\lambda_{j-1} < \beta_1 X_{i,1} + e_{i,1} < \lambda_j;\, \gamma_{k-1} < \beta_2 X_{i,2} + e_{i,2} < \gamma_k\right) \\ &= \Pr\left(\lambda_{j-1} - \beta_1 X_{i,1} < e_{i,1} < \lambda_j - \beta_1 X_{i,1}; \gamma_{k-1} - \beta_2 X_{i,2} < e_{i,2} < \gamma_k - \beta_2 X_{i,2}\right) \\ &= \Psi_2\left[\left(\lambda_j - \beta_1 X_{i,1}\right), \left(\gamma_k - \beta_2 X_{i,2}\right), r\right] - \Psi_2\left[\left(\lambda_{j-1} - \beta_1 X_{i,1}\right), \left(\gamma_k - \beta_2 X_{i,2}\right), r\right] \\ &-\Psi_2\left[\left(\lambda_j - \beta_1 X_{i,1}\right), \left(\gamma_{k-1} - \beta_2 X_{i,2}\right), r\right] + \Psi_2\left[\left(\lambda_{j-1} - \beta_1 X_{i,1}\right), \left(\gamma_{k-1} - \beta_2 X_{i,2}\right), r\right], \end{aligned} \tag{3}$$

where Ψ is the cumulative distribution function.

Parameters in the BOP model can be calculated by maximizing the log-likelihood function and are given by:

$$LL = \sum_{i=1}^{n} \sum_{j=0}^{J} \sum_{k=0}^{K} \delta_{jk} \begin{bmatrix} \Psi_2\left[\left(\lambda_j - \beta_1 X_{i,1}\right), \left(\gamma_k - \beta_2 X_{i,2}\right), r\right] - \Psi_2\left[\left(\lambda_{j-1} - \beta_1 X_{i,1}\right), \left(\gamma_k - \beta_2 X_{i,2}\right), r\right] \\ -\Psi_2\left[\left(\lambda_j - \beta_1 X_{i,1}\right), \left(\gamma_{k-1} - \beta_2 X_{i,2}\right), r\right] + \Psi_2\left[\left(\lambda_{j-1} - \beta_1 X_{i,1}\right), \left(\gamma_{k-1} - \beta_2 X_{i,2}\right), r\right] \end{bmatrix}, \tag{4}$$

where i = 1,2,3, ... , and n is the size of the sample.

The signs of the factors connected with explanatory variables indicate the positive and negative effects of the variable on the results. The positive sign means the probability increases of the most strong result and the probability decreases of the least strong result. In the case of the negative sign, the opposite is true. These coefficients do not determine the quantitative impact of these variables. Also, they cannot be interpreted, in particular for intermediate categories. To determine the influence on intermediate categories, the marginal effects are calculated at the average sample for each category of explanatory variable $\mathrm{X}_{\mathrm{i},1}$ for $y_{\mathrm{i},1}$ as [94,99]:

$$\frac{P(y_{i,1} = j)}{\partial X_{i,1}} = \left[\tau\left(\lambda_{j-1} - \beta_1 X_{i1}\right) - \tau\left(\lambda_j - \beta_1 X_{i,1}\right)\right]\beta_1, \tag{5}$$

where $P(y_{i,1} = j)$ is the probability that bike-sharing system usage is on level j, $\tau(\ldots)$ is the probability mass function of the standard normal distribution, j is the levels of importance ordered by integers, λ is the thresholds.

Thus, the marginal effect of explanatory variable $\mathrm{X}_{\mathrm{i},2}$ for $y_{\mathrm{i},2}$ is given as:

$$\frac{P(y_{i,2} = k)}{\partial X_{i,2}} = [\tau(\gamma_{k-1} - \beta_2 X_{i2}) - \tau(\gamma_k - \beta_2 X_{i,2})]\beta_2. \tag{6}$$

6.3. Bivariate Ordered Probit Model Results

In order to determine the factors affecting the bike-sharing system usage as well as the level of satisfaction connected with the bike-sharing system usage the bivariate ordered probit model was determined. Table 6 to Table 8 present the explanatory variables and descriptive statistics. In turn, Table 9 presents bivariate ordered probit model results. The obtained results show a significant correlation between the bike-sharing system usage as well as the level of satisfaction connected with the bike-sharing system usage. The obtained results seem logical and find confirmation in reality. Regular users of the bike-sharing system were satisfied with the offered services. In contrast to them, people who rarely used the system indicated its disadvantages. In the final form of the model, variables were only included which were significant at the 95% confidence level. The correlation parameter was positive ($p = 0.128$, p-value = 0.027) which allows us to state that a higher level of satisfaction connected with bike-sharing system usage could increase the likelihood of the bike-sharing system usage.

Based on Table 11, it can be concluded that there were 12 significant variables in the model of the bike-sharing system usage and 10 significant variables in the model of the level of satisfaction connected with the bike-sharing system usage. The bivariate ordered probit model results presented in Table 11 represent the general direction of influence of factors determining bike-sharing system usage as well as the level of satisfaction connected with bike-sharing system usage. In turn, Tables 12 and 13 show the numerical values for those variables that had marginal effects for the bivariate ordered probit model. The most desirable group of respondents were those who were characterized by "often" bike-sharing system usage and a "fully" level of satisfaction connected with bike-sharing system usage.

Table 11. Bivariate ordered probit model results.

Variable	**Bike-Sharing System Usage**			**Level of Satisfaction Connected with Bike-Sharing Usage**		
	β	**Standard Error**	p**-Value**	β	**Standard Error**	p**-Value**
Gender	0.315	0.062	0.001	-	-	-
Monthly income (Gross) 2000–4000 (PLN)	-	-	-	0.462	0.215	0.036
Monthly income (Gross) 4001–∞ (PLN)	-	-	-	0.594	0.273	0.002
Travel time(< 30 min)	0.405	0.123	0.006	-	-	-
Trip mode (bicycle)	0.701	0.164	0.001	-	-	-
Trip mode (public transport and bicycle)	0.704	0.178	0.002	-	-	-
Bicycle/e-bike in household	0.11	0.082	0.023	-	-	-
Satisfaction with bike-sharing fees	0.312	0.097	0.018	0.572	0.093	0.000
Bike-sharing station close to home/workplace	0.629	0.201	0.003	0.342	0.171	0.022
Familiarity with bike-sharing system	0.736	0.101	0.001	0.638	0.112	0.034
Saving travel cost by bike-sharing	-	-	-	0.407	0.173	0.022
Encouragement of green travel	0.301	0.250	0.00	-	-	-
Flexible route by bike-sharing system	0.328	0.152	0.010	0.418	0.162	0.002
Wasting travel time by bike-sharing	−0.159	0.101	0.009	-	-	-
Great effort on the introduction to the public	0.482	0.146	0.000	0.389	0.099	0.001
Easy to check-in	-	-	-	0.378	0.141	0.002
Easy to check-out	-	-	-	0.302	0.159	0.001
ρ	0.128	0.036	0.027	-	-	-
μ_1	2.789	-	-	-	-	-
μ_2	4.276	-	-	-	-	-
θ_1	−0.904	-	-	-	-	-
θ_2	1.538	-	-	-	-	-
Number of observations	1584					
Log-likelihood convergence	−1622.03					

Table 12. Numeric values for variables that had marginal effects for the bivariate ordered probit model in the case of bike-sharing system usage.

Bike-Sharing System Usage	Rarely	Medium	Often
Gender	−0.1172	0.0463	0.0709
Trip mode (bicycle)	−0.2358	0.0250	0.2108
Trip mode (public transport and bicycle)	−0.3718	0.0246	0.3472
Bicycle, e-bike in household	−0.0983	0.0681	0.0302
Travel time (< 30 min)	−0.1426	0.0471	0.0955
Familiarity with bike-sharing system	−0.2199	0.1082	0.1117
Bike-sharing station close to home/workplace	−0.3018	0.0967	0.2051
Satisfaction with bike-sharing fees	−0.0938	0.0429	0.0509
Wasting travel time by bike-sharing	0.0892	−0.0572	−0.0320
Encouragement of green travel	−0.1702	0.0857	0.0845
Flexible route by bike-sharing	−0.0798	0.0610	0.0188
Great effort on the introduction to the public	−0.3219	0.0529	0.2690

Table 13. Numeric values for variables that had marginal effects for the bivariate ordered probit model in the case of level of satisfaction connected with bike-sharing system usage.

Level of Satisfaction Connected with Bike-Sharing System Usage	Lack of	Average	Fully
Familiarity with bike-sharing	−0.3081	−0.2138	0.5219
Monthly income (Gross) 2000–4000 (PLN)	−0.0078	−0.2394	0.2472
Monthly income (Gross) 4001−∞ (PLN)	−0.0143	−0.3192	0.3335
Bike-sharing station close to home/workplace	−0.0074	−0.0903	0.0977
Satisfaction with bike-sharing fees	−0.0328	−0.2790	0.3118
Flexible route by bike-sharing	−0.0085	−0.2014	0.2099
Saving cost by bike-sharing	−0.0261	−0.1839	0.2100
Great effort on the introduction to the public	−0.0326	−0.2106	0.2432
Easy to check-in	−0.0267	−0.1523	0.1790
Easy to check-out	−0.0084	−0.0623	0.0707

7. Discussion

The analysis presented in the article makes it possible to state that the bike-sharing system plays the role of an element enhancing sustainable mobility in the city. The data presented in the paper for Warsaw (Poland) indicated that from year to year the number of bike-sharing system users increases. These users are mainly young people in a group of age 19–45, using standard bikes, most often in the afternoon (from 3:00 p.m. to 9:00 p.m.) and mostly on working days, in the months from April to September. An important aspect is that the bike-sharing system has been popular among users and that more people use it. Therefore, a dense network of conveniently located bike-sharing stations should be provided in the city. Also, the quality of the bike-sharing system should be an adjustment to the users' expectations. Hence, this article presented an analysis of the factors the bike-sharing system usage as well as the level of satisfaction connected with bike-sharing system usage. The results of the analysis showed that there is a strong positive correlation between these variables. The obtained results can be helpful for carrying out activities to increase bike-sharing system usage as well as the level of satisfaction connected with bike-sharing system usage. The analysis presented in this article allowed us to formulate the following conclusion that respondents do not use often the bike-sharing system (they asked about the frequency of using the system, the answers "average" and "rarely" were, respectively, 38.38% and 40.28%), nevertheless, most of the respondents were fully satisfied with the functioning of the bike-sharing system and assessed it at a very high level (59.28%). A total of 37.88% of respondents rated the level of satisfaction connected with bike-sharing usage at an average level without indicating the disadvantages or advantages of the system. Meanwhile, respondents who were not satisfied with the functioning of the system represented 2.84% of the total. Conducted analyses allowed us to establish that there is a significant correlation between bike-sharing system usage as well as the level of satisfaction connected with bike-sharing system usage. The obtained results seem logical and find confirmation in reality. Regular users of the bike-sharing system are satisfied with the offered services. In contrast to them, people who rarely use the system indicate its disadvantages. The correlation parameter was positive (p = 0.128, p-value = 0.027) which makes it possible to state that a higher level of satisfaction connected with bike-sharing system usage could increase the likelihood of bike-sharing system usage. Analysis has shown that men use the bike-sharing system 7% more often than women. The obtained conclusion is consistent with the results of previous research conducted by E. Fishman [100], J. Pucher et al. [101], C.C. Hsu et al. [102]. Moreover, respondents who indicated that they have a bike or e-bike in their households more often used the bike-sharing system. This result can be explained by the fact that those respondents are familiarized with cycling, so they willingly decide to use a bike during their journey. The marginal effect indicated that the probability of bike-sharing system usage for this group is about 3% higher than respondents without a bike or e-bike in their household. This conclusion is consistent with the obtained results by other authors, e.g., by Y. Guo et al. [69].

Respondents used the bike as well as public transport and bike on their daily journey, they often used the bike-sharing system. Marginal effects indicated that the probability of bike-sharing system usage increases by about 21%–35% for people who travel with these two modes of transport. Similar research results are presented in the paper R.B. Noland et al. [103]—metro stations located a short distance from the bike-sharing stations contributed to increasing the number of trips. In turn, respondents who indicated that their travel time was less than thirty minutes were 9.55% more likely to use the bike-sharing system than respondents whose travel time was longer. This conclusion is also confirmed by earlier scientific papers in which travel time using a bike was usually about 30 minutes [104–106].

In the case that the availability of the bike-sharing stations is in the distance up to 500 m of home, workplace, school, university, then the probability of "often" bike-sharing system usage increases by 20.51%. Additionally, the probability of full satisfaction connected with bike-sharing system usage increases by 9.77%. M. Austwick et al. [36], Y. Guo et al. [69], and E. Eren et al. [107] obtained similar results in their works. They indicated that an increasing number of bike-sharing stations cause increasing bike-sharing system usage, whereas the authors W. El-Assi et al. [108] indicated that the distance between stations affects the number of trips using a bike-sharing system.

A total of 11.17% of respondents who knew the rules of the bike-sharing system well used the bike-sharing system more often. In addition, the probability of their full satisfaction increased by as much as 52.19%. This conclusion is important because it indicates the need to familiarize the society with the principles of the functioning and operation of the bike-sharing system. Activities in this area may be conducted by information campaigns or social consultations. These types of activities should contribute to increasing the number of bike-sharing system users. Respondents who accepted and who expressed their satisfaction with the current fees for using the bike-sharing system were characterized by 5.09% higher probability of often using the bike-sharing system. Additionally, they were characterized by 31.18% higher probability of full satisfaction connected with bike-sharing system usage. This conclusion is consistent with the results of the works of A. Faghih-Imani and N. Eluru [51], and E. Fishman [100]. The results from these scientific studies showed the relationship between the bike-sharing system usage and respondents financial savings. As shown in the work of Z. Li et al. [109], people usually minimize travel costs.

Respondents who did not want to incur a loss of time in connection with a cycling trip were 3.20% less likely to choose this form of transport. In turn, a great effort connected with the introduction of the bike-sharing system to the city in order to enhance to sustainable mobility also increased the bike-sharing system usage and level of satisfaction respectively by 26.90% and 24.32%. This conclusion confirms the effectiveness of existing social campaigns and all other activities aimed at encouraging the local community to travel using pro-ecological forms of transport and promotes sustainable transport development. Respondents who were environmentally friendly and who support ecological forms of transport were 8.45% more likely to often use bike-sharing systems.

Respondents who recognized the flexible route offered to them by the bike-sharing system tended to use it often and were fully satisfied with bike-sharing system usage. Marginal effects in these cases show that the probability of often using bike-sharing systems and full satisfaction connected with bike-sharing system usage increased in this case by 1.88% and 20.99%, respectively. Respondents also indicated that easy check-in and easy check-out increase the probability of full satisfaction connected with bike-sharing system usage. In this case, the marginal effects show that the probability of full satisfaction increased by 17.90% and 7.07%, respectively. Results of analysis also indicated that monthly income gross was positively correlated with the level of satisfaction connected with bike-sharing system usage. For the respondents with a monthly gross income of 2000–4000 PLN, marginal effects showed that the probability of full satisfaction increase by 24.72%. In the case of respondents with monthly income gross over 4000 PLN the probability of full satisfaction increased by 33.35%. A similar conclusion was found from research carried out by K.M. Gámez-Pérez et al. [110]. In this work it was indicated that as the socioeconomic level increases, the likelihood that a person will be a user of a bike-sharing system decreases.

However, the presented system is not without defects. Its main disadvantages include an insufficient number of bikes for the disabled, tricycles that could be used by older users, or bikes with manual drive. In addition, it should consider extending the season by winter, especially in mild winter. It is also critical to approach children's bikes and the security level offered by the system for this type of user. This disadvantage of the system is also the malfunction of bikes and stations, which the respondents pointed out in their answers. As reported in [111], there were 59,380 reports on bike defects (which accounted for 0.92% of all rentals) and 22,861 reports of station defects in 2018. There was also a decrease in the popularity of the bike-sharing system associated with the increase in the popularity of electric scooters.

In addition, future analysis would have to be done of the city's configuration which might contribute to strengthening the obtained results about the most integrated bike-sharing routes, as well as the level of connectivity within the bike-sharing network. In Warsaw agglomeration, where there are several transport subsystems (pedestrian, bike, individual, and public transport), ensuring a high degree of their integration is of particular importance. This integration must consist of the continuous modernization of transport nodes so that users of the bike-sharing system in Warsaw can get anywhere and that they have places to park the bike. The customer service systems should be improved that sometimes does not work well. Particular importance will be attributed to the qualitative change in the functioning of the main transport nodes related to the railway system and the increase in the number of stations and bikes at stations. To encourage new customers to use these solutions, the cost of use should not be forgotten, which must be at a level achievable by every resident. It can certainly be stated that the Vertuilo system is integrated with other modes of urban transport. It makes it faster and healthier to arrive at the previously selected destination. Warsaw is perceived as a city which is cyclist-friendly and choosing innovative solutions that are friendly to the natural environment, thanks to investments and implementation of new projects in the bike-sharing system.

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