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## **P&R PARKING AND BIKE-SHARING SYSTEM AS SOLUTIONS SUPPORTING TRANSPORT ACCESSIBILITY OF THE CITY**

**Summary.** The transport accessibility of cities decreases with the increase in road traffic. Planners, traffic engineers, and road managers are looking for solutions that will reduce congestion on city streets without limiting transport accessibility to the city center. The article presents an overview of solutions used in Poland and abroad that aim to encourage people who travel by car to the city center to use other means of transport. The solutions were identified that can contribute to reducing road traffic in the city without limiting its transport accessibility based on the area inventory in Krakow. The next part of the article analyzes the use of P&R parking and the bike-sharing Wavelo system in Krakow in 2018. The results of the conducted analyses indicate that the most entrances to the P&R parking in Krakow were in the morning hours, whereas the most exits from these parking were in the afternoon. The holiday months were characterized by a lower use of parking space compared with the remaining months. These conclusions may indicate that the people using the analyzed parking lots are mainly commuters. On the contrary, the analysis of the use of the bike-sharing Wavelo system in Krakow allows for the conclusion that a large number of people used rental bikes for short journeys. These trips can complement the journeys made with the use of public transport or as a continuation of the journey after leaving the car in the P&R parking. Investments and development of this type of solutions may be an incentive for people traveling by car to use another means of transport.

### **1. INTRODUCTION**

Ensuring transport accessibility at a time when city traffic causes traffic jams is a challenge for city authorities. The main goal of the national transport policy is to increase territorial accessibility and improve the safety of road users and the efficiency of the transport sector by creating a coherent, sustainable, and user-friendly transport system in the national (local), European, and global dimension. Actions that limit car traffic in built-up areas cannot (should not?) reduce transport accessibility to the city center.

The transport infrastructure affects the communication behavior of residents. The decision about the necessity for the transport user to move leads to an assessment of the available means of transport. The choice of the means of transport is determined by the transport accessibility of the transport system. Owning a car, access to it, and the quality of public transport have a significant effect on the mobility of city residents. The possibility of integrating the services of both means of transport is beneficial not only for the transport system and the natural environment but also for users and transport organizers. An interchange node is a place where there is an integration of several modes of transportation (i.e. a place that enables a convenient change of means of transport). The interchange node should be equipped with the necessary infrastructure for passenger service, in particular, parking spaces, public transport stops, ticket sales points, and information systems enabling familiarization in particular with the timetable, communication line, or communication network.

Fig. 1 shows a schematic view of tools that can contribute to improving the accessibility of public transport. Shaping the space of the interchange node should be based mainly on the safety of transport (the need to cross the intersection), ease of walking from the point where the journey by one means of transport ends to the point where the journey by other means of transport begins (walking time), and passenger information (including the public transport vehicles - dynamic information on possible transfers, departure times and bus stops, clear marking of public transport stops, parking, and bike-sharing stations). These issues are important for the passenger because changing the means of transport to another is for him/her time, space, and tariff cost.

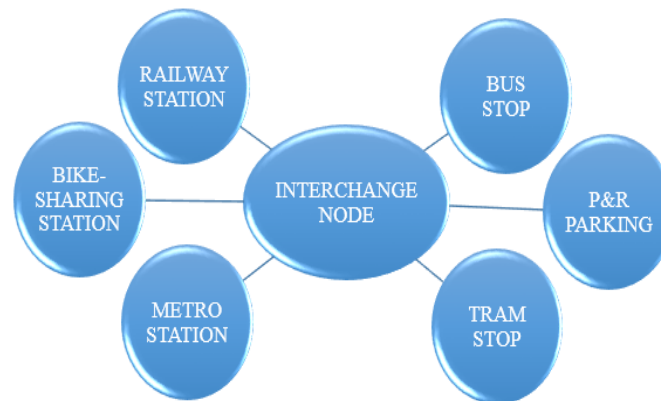


Fig. 1. Elements of the interchange node

Alternative means of transport to cars should ensure transport accessibility to the city center. The main aim of the article is to present solutions that will encourage car users to travel with the use of means of transport that do not contribute to traffic congestion in the city center and at the same time ensure transport accessibility to these areas. The first part of the article provides an overview of solutions aimed at reducing traffic congestion in the city center and ensuring a high level of accessibility to these areas. Then, the article presents the results of analyses of the use of two such solutions, i.e. the P&R parking and the bike-sharing system in Krakow. The analyses are based on data from 2018. The following part of the article presents an analysis of the pedestrian accessibility of the analyzed solutions.

## 2. REVIEW OF SELECTED SOLUTIONS INCREASING TRANSPORT ACCESSIBILITY TO THE CITY CENTER

This chapter presents solutions that contribute to reducing road traffic in the city, and at the same time ensure transport accessibility to the city center. These solutions are system parking and shared mobility. Moreover, activities were presented that may discourage people from traveling by car from using it in the city center, i.e., parking fees, city entry fees, traffic calming zones, etc. There are also presented solutions that can improve movement in built-up areas with a car.

### 2.1. Review of selected solutions increasing transport accessibility in Poland and around the world

In domestic and foreign literature, many works can be found that indicate the advantages of traveling by means of transport other than a car [1-3]. Actions aimed at reducing the number of journeys made with cars in cities can be divided into actions aimed at the following:

- encourage travelers to use alternative means of transport (Table 1),
- discourage or prevent the entry of cars into the city center (Table 2).

From the group of solutions that are used to manage traffic in cities and may contribute to the more efficient movement of a car in the city are Intelligent Transport Systems (ITS). ITS is a wide range of various technologies (telecommunications, information technology, automatic, and measurement) and management techniques used in transport to protect the lives of road users, increase the efficiency of the

transport system, and protect natural resources [27, 28]. The use of ITS tools may contribute to the reduction of road congestion in the city, improvement of traffic safety in the city, and reduction of the negative effect of transport on the environment.

Table 1

The solutions encouraging people traveling by car to use alternative means of transport

Solution	Characteristic
Park & Ride parking	System parking located on the outskirts of the city. Its main goal is to encourage drivers to leave their cars outside the city center and continue their journey using other means of transport, primarily public transport. The results of studies on the use of P&R parking available in the literature indicate that people who leave their vehicles are people who commute to work [4-6].
Kiss & Ride parking	System parking located near the train station, bus or tram stops, and at the airport. These parking are designed for short and free parking, which are mainly used for picking up a passenger. In the literature, there is little work related to the analysis of this type of parking, and the existing research in this area mainly concerns the increase in the accessibility of public transport (including railways) [7] and the use of parking space.
Bike & Ride parking	The system parking is located near the train station, as well as bus or tram stops, and can also be part of P&R parking. In this solution, the goal is to reach the parking by bike, leave it there, and continue the journey using means of public transport. This solution may contribute to increasing the attractiveness of public transport [8]. In the literature on the subject, B&R parking has been mentioned only a few times, e.g. Ch. Jingxu et al. [9] presented an analysis of the preferences of users of this type of parking. The results allow for better plan their location, which may contribute to increasing the number of journeys made with the use of public transport. In turn, the work of G. Akar and K. J. Clifton [10] indicated that the use of B&R parking may be influenced by increasing the sense of safety of cyclists.
Car-sharing system	This system is designed to share a car. As indicated in the literature on the subject, one of the positive results of introducing this solution was the sale of their car by some people or the resignation from purchasing it. This may contribute to the reduction of the number of people who want to have their own car [11-13]. The work of F. F. Dias et al. [14] presents the results of the survey which show that the car-sharing system is used mainly by young people with higher education.
Bike-sharing system	This system allows users to access public bikes at rental stations or at various points, depending on the generation [15-17]. Research conducted in the field of the bike-sharing system shows that users rent bikes mainly for short periods (about 30 minutes) [18].
Scooter-sharing system	The system that allows to rent a scooter at a specific location [19]. This system is attractive for short journeys or as a supplement to journeys with the use of public transport [20-21].

## 2.2. Review of selected solutions increasing transport accessibility in Krakow

Krakow is a city located in the Lesser Poland Voivodeship. The automotive index in 2018 was 0.64 car/inhabitant [29]. Public transport in Krakow is characterized by a wide offer. There are 24 city tram lines and 85 city bus lines, 72 agglomeration bus lines, 3 night tram lines, and 20 night bus lines [30]. In addition, residents can move using railway transport consist of three lines of the Fast Agglomeration Railway (in polish: SKA).

In March 2020, an area inventory was carried out in Krakow, which was aimed at identifying solutions in public transport allowing for efficient passenger service, which affects transport

accessibility. Owing to heavy traffic in the city, the movement of buses on the same lanes as cars generates delays in the operation of these vehicles. Therefore, buses running on the streets in Krakow can use separate bus lanes as well as shared lanes and stops for tram and bus. This solution separates car traffic from bus traffic, thanks to which means of public transport do not stand in traffic jams. Moreover, to increase the attractiveness of public transport, two-way stops have been used, which integrate the bus and the tram [30]. In Krakow, there are also Viennese stops (tram-bus or tram), which are designed when the tram track is separated from the pavement by a road. The structure of Viennese stops consists of raising the road in the area of the stop to the level of the pavement. The solution enables easier access to and boarding the tram, which slows down traffic and increases pedestrian safety. Passengers may be picked up at Kiss and Ride (K&R) parking, which are designed to lift the person transferring to the public transport. In Krakow were designed four such parking, which allow drivers to stop for 1 minute or 3 minutes. The density of cycling infrastructure affects the availability of this means of transport. According to the data presented in Mobile Krakow, Public Transport Authority in Krakow [31], the bicycle infrastructure in Krakow is extensive. The cyclists can use separate bicycle paths or pedestrian and bicycle paths as well as on sidewalks and streets where bicycle traffic is allowed. Additionally, bicycle lanes and counter-lanes have been designed in many places.

Table 2

The solutions aimed at discouraging or preventing the entry of car users into the city center

Solution	Characteristic
Tempo 30 zone	Physical limiters are usually placed in these zones to force the drivers to reduce their speed [22]. Drivers discouraged by such solutions may decide to choose a different route or give up traveling by car.
Shared space zone (so-called Woonerf, Dutch: street to live)	This zone is a public space with the function of a street, parking, and promenade, without separation of car, bicycle, and pedestrian traffic [23]. Drivers discouraged by such solutions may decide to choose a different route or give up traveling by car.
Parking fees in downtown areas	This solution is aimed at increasing the turnover of parking spaces, which will allow more drivers to find a parking space. Proper management of parking fees in the city center reduces the number of vehicles in this area.
Entrance fees to the city	In the case of this solution, a fee may be charged for entering an area of the city with high car traffic, whereas other solutions do not discourage drivers from traveling using other means of transport than car [24].
Traffic ban on the streets in the city center	This solution consists in preventing the entry of vehicles into the city area, which is a critical point on the road network (e.g. in Oslo [25]). In Poland, city authorities have so far not decided to charge for entering the city. Therefore, they decide to build Paid Parking Zones (in polish: SPP) [26].

Until 31<sup>th</sup> December 2019, in Krakow, there was a bike-sharing system that was station based - Wavelo - operated by BikeU. The Wavelo system is a system of maintenance-free bicycle rentals. The system client can take bicycle from one station and return at any other station. According to data from 19.03.2019, it consisted of 168 stations (including one mobile) [32]. Fig. 2 presents schematically the location of the bike-sharing Wavelo system stations. Fig. 2 shows that bike-sharing stations were located mainly in the city center. Another applied solution is P&R parking, which, in accordance with the concept of this system, are located on the outskirts of the city (Fig. 3). In Krakow, there are four P&R parking. These include the following:

- P&R Bieżanów (110 parking spaces including 5 for people with disabilities and 2 for electric car);
- P&R Kurdwanów (167 parking spaces including 7 for people with disabilities and 4 for electric car);

- P&R Czerwone Maki (196 parking spaces including 4 for people with disabilities); and
- P&R Mały Płaszów (165 parking spaces including 7 for people with disabilities and 2 for electric car).

By 2022, the construction of the fifth parking (P&R Bronowice) is planned. The manager of the parking is the company Urban Infrastructure in Krakow.

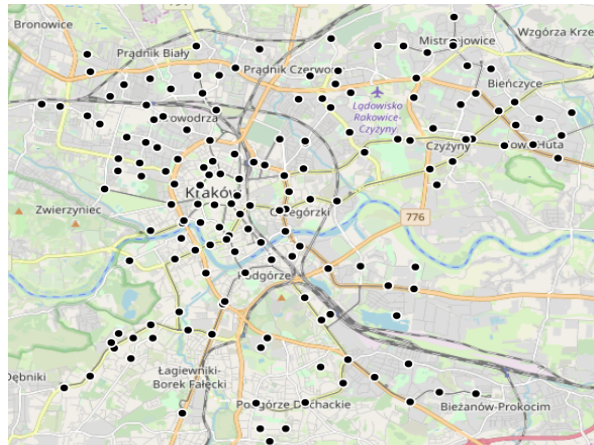


Fig. 2. Location of the bike-sharing Wavelo system stations in Krakow

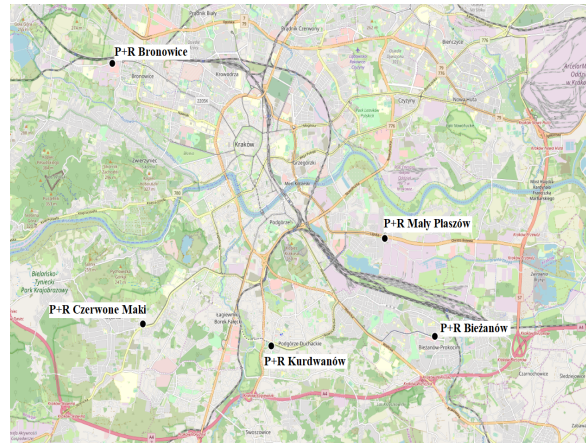


Fig. 3. Location of P&R parking in Krakow

### 3. ANALYSIS OF THE USE OF PARKING P&R AND THE BIKE-SHARING WAVELO SYSTEM IN KRAKOW

This part of the article presents an analysis of the use of P&R parking and the bike-sharing Wavelo system in Krakow in 2018. Data for the analysis of three parking: P&R Biezanów, P&R Kurdwanów, and P&R Czerwone Maki, were obtained from the company Urban Infrastructure in Krakow and covered each day of 2018. The P&R parking Mały Płaszów was not included in the analysis because it was opened in April 2019, whereas the construction of the P&R parking Bronowice is planned. Data for January and February 2018 were incomplete, and therefore these data were not used for analysis. Analysis of the use of P&R parking included the determination of the following:

- the average number of entries and exits of vehicles in particular hours, divided into working days, Saturdays and Sundays, and
- the use of parking space in particular months.

However, the analysis of the bike-sharing Wavelo system was based on data obtained from the Public Transport Authority in Krakow [31]. The data also included every day of 2018. The analysis of the use of the bike-sharing system included the determination of the following:

- the average travel distance during one rental, divided into days of the week,
- the average travel time during one rental, divided into days of the week,
- the total number of bike rentals divided into months, and
- the total number of rentals in particular periods of the day in May.

#### 3.1. Analysis of the use of selected parking P&R in Krakow

Fig. 4 shows the number of vehicle entries and exits to/from the analyzed parking in particular hours of the day divided into days of the week. By analyzing the data in Fig. 4, it can be concluded that most drivers enter the analyzed parking in the morning. In the case of the P&R parking Biezanów, these hours are 06:00-08:00, whereas for the P&R parking Kurdwanów and P&R parking Czerwone Maki are 06:00-09:00. The P&R parking Czerwone Maki was characterized by the greatest number of entries. Most vehicles exit the analyzed parking in the afternoon. In the case of the P&R parking Biezanów and P&R parking Kurdwanów, these hours are 15:00 - 18:00, whereas in the P&R parking Czerwone Maki are 15:00 - 19:00. Moreover, analyzing the data, it can be concluded that drivers park their vehicles in the

analyzed parking more often on working days than on weekend days. More than 80% of entries to the analyzed parking were on working days. This indicates that people using P&R parking are people who commute to work, school, or university.

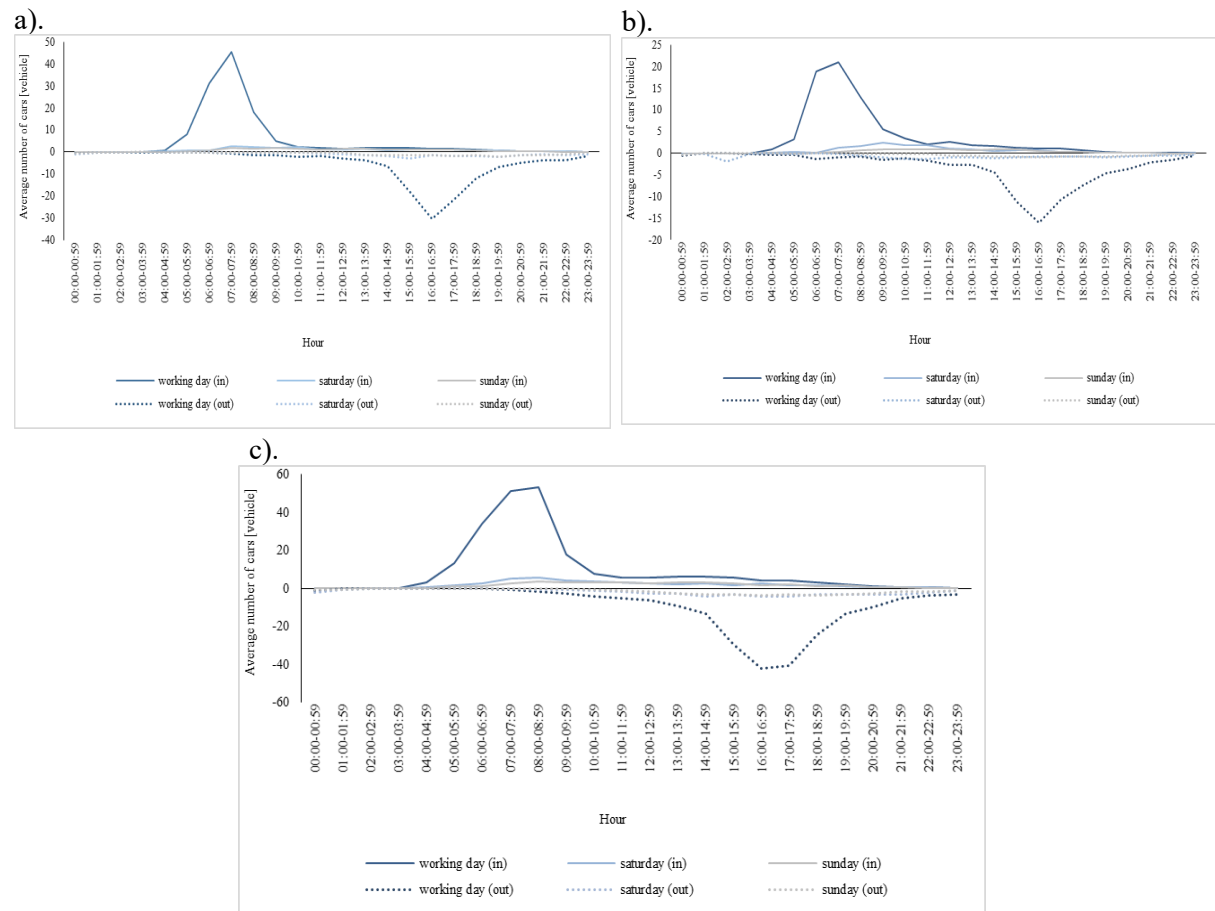


Fig. 4. The average number of vehicle entries and exits to/from the parking: a) P&R Biezanów; b) P&R Kurdwanów; c) P&R Czerwone Maki, at particular hours divided into working days, Saturdays, and Sundays

Fig. 5 presents the use of the area of the analyzed parking in particular months of 2018 on an average working day. The P&R parking Kurdwanów is characterized by the smallest use of parking space. In the case of this parking, one can also notice a large variation in the use of space in particular months. The smallest differences in the use of parking space in particular months can be observed in the P&R parking Biezanów. In the case of August, it can be noticed that there is the lowest number of parked vehicles in all analyzed parking. In the P&R parking Kurdwanów, it is even July and September, whereas in the P&R parking Czerwone Maki is July. Less use of parking space in the summer months is confirmed by the fact that the greatest number of people using P&R parking are people commuting to work. The highest use of the parking space was in the P&R parking Biezanów in October, whereas in the P&R parking Kurdwanów and P&R parking Czerwone Maki - in November.

### 3.2. Analysis of the use of the bike-sharing system in Krakow

As stated in the Krakow transport website [33] 987,203 rentals were made in the bike-sharing system in Krakow in 2018. Fig. 6 shows the average length of trips using the bike-sharing system on particular days of the week in 2018. Analyzing the data, it can be concluded that the average length of one trip in the Wavelo system is approximately 3.50 km on working days and Saturdays, whereas on Sundays, this value is approximately 4.00 km. In turn, Fig. 7 shows the average travel time using the bike-sharing

Wavelo system on particular days of the week in 2018. Travel time by the bike-sharing system on working days was on average around 20 minutes. However, on the weekend days, this value ranged from 25 to 30 minutes.

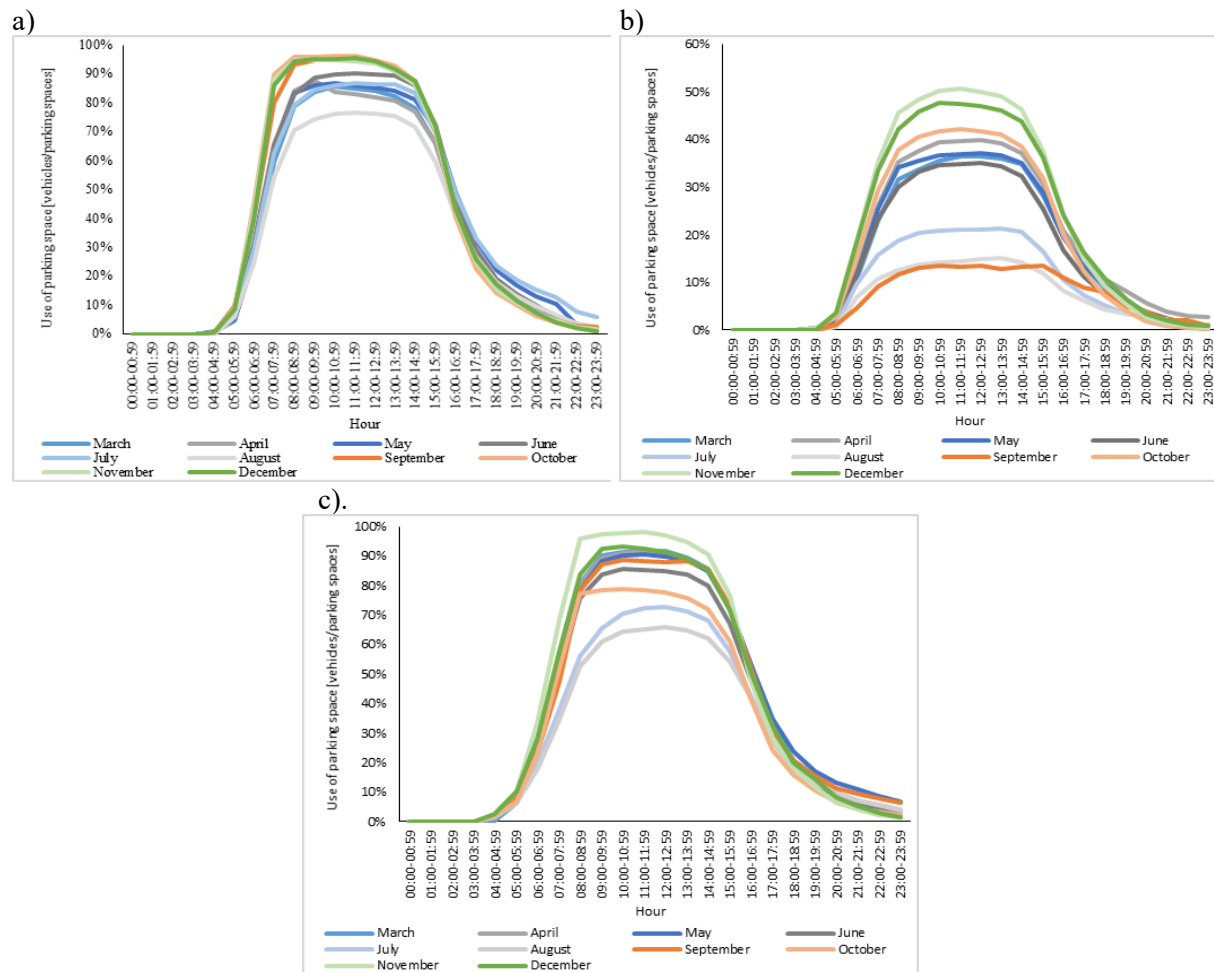


Fig. 5. Use of the parking space: a) P&R Biezanów; b) P&R Kurdwanów; c) P&R Czerwone Maki, on working days in particular months of 2018

Fig. 8 presents the average number of bike rentals in the Wavelo system during one day in particular months. The most rentals were registered in the months from April to June, whereas the least from January to March, and in November and December, which is related to the unfavorable weather conditions prevailing in those months in Poland.

The lower number of bike rentals in July and August compared with the spring months is probably related to the holiday season and trips of residents to holidays outside the city. Owing to the fact that the largest number of bike rentals was in May 2018, Fig. 9 shows the total number of rentals and returns in the bike-sharing Wavelo system in Krakow in this month in particular periods of the day. The greatest number of rentals and returns was between 15:00 and 19:00, whereas the lowest was between 11:00 and 15:00. It can be concluded that people using the bike-sharing Wavelo system in Krakow used them for recreational trips.

#### 4. PEDESTRIAN ACCESSIBILITY OF ANALYZED SOLUTIONS

This section presents an analysis of pedestrian accessibility to selected areas. First, the equivalent distance from the P&R parking to the nearest bike-sharing station in Krakow is presented. Then, maps of pedestrian accessibility for P&R parking and bike-sharing stations in Krakow were presented.

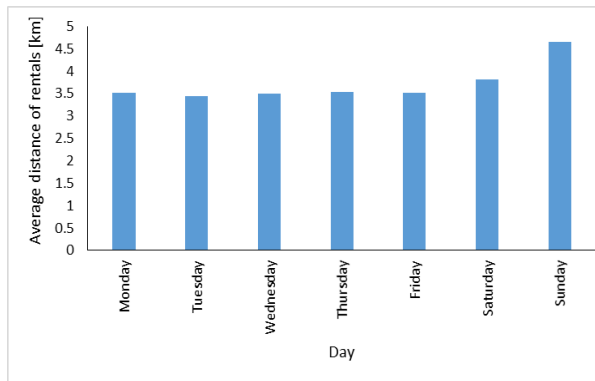


Fig. 6. Average travel distance using the bike-sharing Wavelo system in Krakow on particular days of the week in 2018

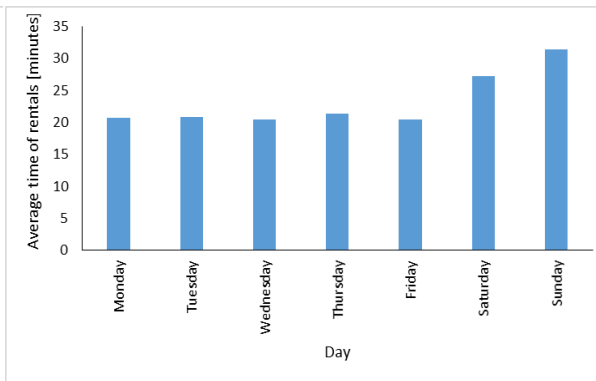


Fig. 7. The average travel time using the bike-sharing Wavelo system in Krakow on particular days of the week in 2018

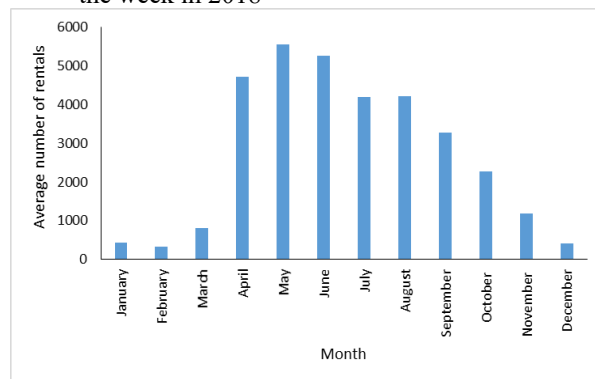


Fig. 8. The average number of rentals in the bike-sharing Wavelo system in Krakow in particular months

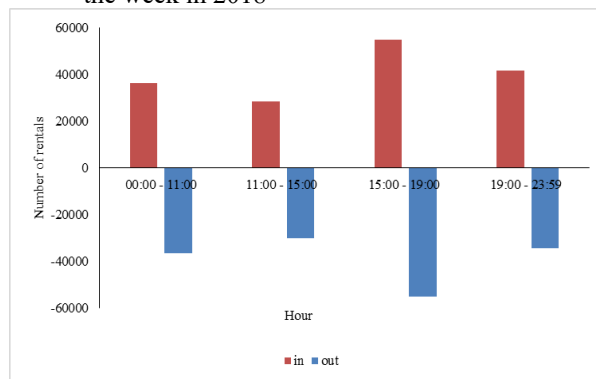


Fig. 9. The total number of rentals and returns in the bike-sharing Wavelo system in Krakow in May 2018 in particular periods of the day

Equivalent distance (EWD) is a measure that allows calculating the distance between two points, taking into account the inconvenience to pedestrians in their way, such as crossing the street or the need to overcome stairs. The formula for EWD was proposed by P. Olszewski in a work from 2005 [34]:

$$EWD = DISTW + 55.4 \cdot NCROS + 2.81 \cdot NSTEP + 36.3 \cdot NCONF [m] , \tag{1}$$

where EWD - equivalent distance [m]; DISTW - real walking distance [m]; NCROS - number of street crossings in one level [piece]; NSTEP- number of stairs [step], and NCONF - number of collisions with vehicular traffic along the route [piece].

However, in the work from 2008, P. Olszewski [35] presented the following formula:

$$EWD = DISTW + 42.8 \cdot NCROS + 2.7 \cdot NSTEP + 26.4 \cdot NCONF [m] , \tag{2}$$

where EWD - equivalent distance [m]; DISTW - real walking distance [m]; NCROS - number of street crossings in one level [piece]; NSTEP - number of stairs [step], and NCONF - number of collisions with vehicular traffic along the route [piece].

In this article, EWD calculations were performed based on the formula (2). Table 3 shows the equivalent distances of pedestrian access from the analyzed parking to the nearest bike-sharing stations in Krakow.

Table 3

Equivalent distances from the analyzed P&R parking to the nearest bike-sharing stations in Krakow

Parking	P&R Biezanów	P&R Kurdwanów	P&R Czerwone Maki
Distance			
Real [m]	524.0	212.0	170.0
Equivalent [m]	576.8	697.9	680.2



The assumption to calculate the equivalent distance was that the driver was in the center of the parking. The data presented in Table 3 shows that the P&R parking Biezanów is characterized by the greatest real distance from the nearest bike-sharing station. At the same time, the value of the equivalent distance for this parking is the smallest. Despite the fact that from the other two parking lots, P&R Kurdwanów and P&R Czerwone Maki, to the nearest bike-sharing stations, the real distance is less than twice that in the P&R parking Biezanów, the equivalent distance is more than 100 m longer. Considering the equivalent distance between P&R parking and the nearest bike-sharing station, this accessibility is useful in a situation where, e.g., someone using the bike-sharing system reaches the bike-sharing station nearest P&R parking and then uses the available form of public transport on a multimodal node, which also includes P&R.

In the case of P&R parking, an important aspect for the driver is that the change of the means of transport from the point where the journey by car ends to the point where the journey begins by means of public transport is comfortable, efficient, and safe. The QGIS program was used to analyze pedestrian accessibility. Based on spatial development and transport infrastructure data, it determines the reach of a pedestrian for a specific time or distance variants. The purpose of the construction of the P&R parking is to enable drivers to leave their car in the P&R parking and continue their journey using alternative forms of transport, i.e. public transport or the shared mobility systems. There are tram stops (20-120 m) and bus stops (50-80 m) near the analyzed P&R parking. The Rapid Agglomeration Railway stations are not located near the analyzed P&R parking (the closest stations are 800-3,000 m from the analyzed P&R parking). In the case of shared mobility, only bike-sharing stations are fixed (in the case of e.g. a scooter or scooter rental system, it is possible to leave them anywhere). The bike-sharing stations are located within a distance of 150-700 m from the analyzed P&R parking. In view of the above, Fig. 10 presents the analyzed parking with designated isochrones of pedestrian access in two variants, 5- and 10-minute walk, and the location of the nearest bus and tram stop, as well as bike-sharing stations.

As can be seen, in the case of all analyzed parking, the nearest public transport stop is located in the 5-minute pedestrian access isochrone from the P&R parking. The nearest bike-sharing station is located in the isochrone of 10 minutes to the P&R parking Biezanów. In the case of the other two parking lots, P&R Kurdwanów and P&R Czerwone Maki, the nearest bike-sharing station is located in the 5-minute pedestrian access isochrone. Pedestrian accessibility was also determined for the bike-sharing station near the analyzed P&R parking with the use of isochrones in two variants, 5 and 10 minutes, for pedestrian access (Fig. 11).

For the analyses, the bike-sharing stations located near the analyzed parking lots were selected. As can be seen in the case of the P&R parking Biezanów, there is only one bike-sharing station within walking distance in both analyzed variants. However, in the parking lots P&R Kurdwanów and P&R Czerwony Maki, there is one bike-sharing station within a 5-minute walk, and in the 10-minute variant, 2 bike-sharing stations.

## 5. CONCLUSIONS

Alternative means of transport to the car should ensure transport accessibility to the city center. The article presents solutions that may encourage car users to travel using other means of transport. These solutions do not contribute to road congestion in the city center and at the same time ensure transport accessibility to these areas.

The analysis of the use of the P&R parking and the bike-sharing Wavelo system in Krakow show the effectiveness of the activities carried out to encourage Krakow residents to use other means of transport than a car. Drivers most often entered the P&R parking in Krakow in the morning (at the P&R parking Biezanów between 06:00 and 08:00, and at the P&R parking Kurdwanów and P&R parking Czerwone Maki between 06:00 and 09:00). However, most vehicles existed in the afternoon (from P&R parking Biezanów and P&R parking Kurdwanów - from 15:00 to 18:00, and from the P&R parking Czerwone Maki from 15:00 to 19:00). Moreover, on working days, there were more vehicle entries to the analyzed parking than in the case of weekend days. The holiday months were characterized by lower use of parking space compared with the remaining months. The place of residence of the parking P&R users

was not analyzed. However, it can be concluded that the vast majority of people who use the analyzed P&R parking in Krakow are commuters.



Fig. 10. Pedestrian accessibility for the parking: a) P&R Bieżanów; b) P&R Kurdwanów; and c) P&R Czerwone Maki

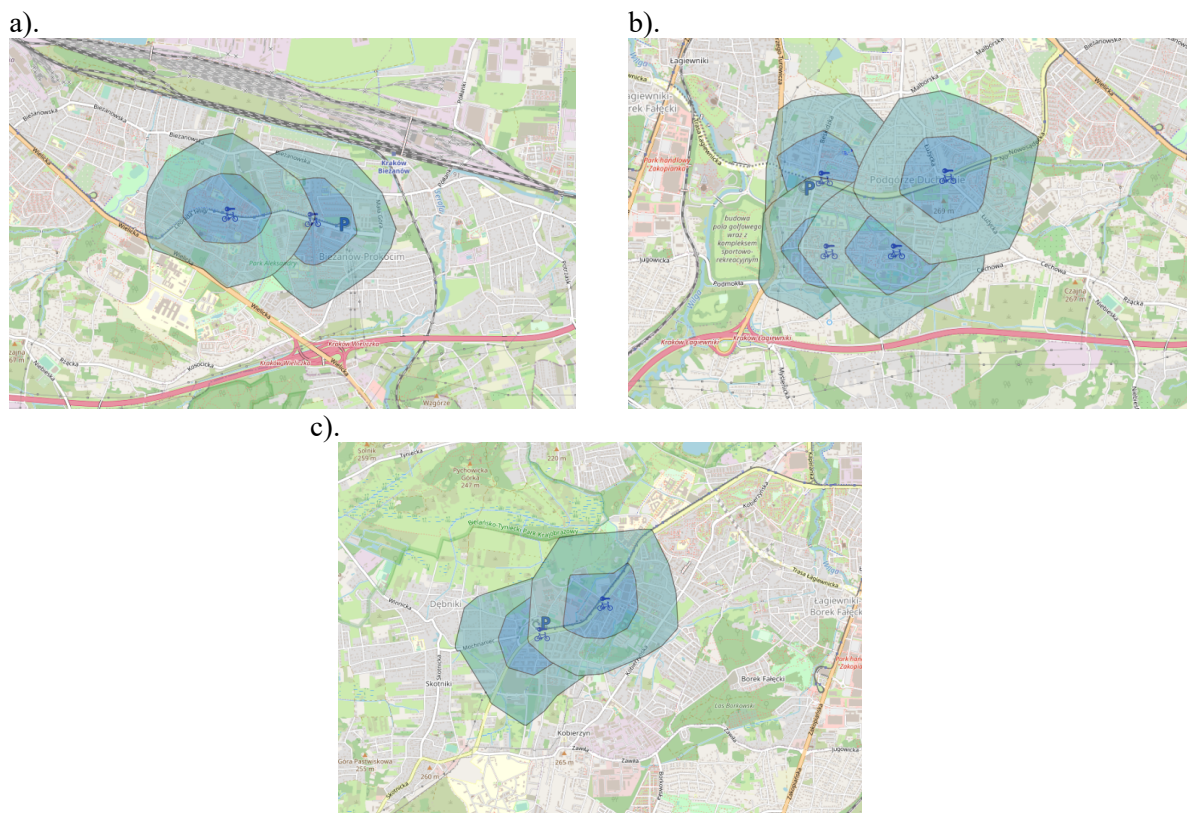


Fig. 11. Pedestrian accessibility in two variants: 5 minutes and 10 minutes to the bike-sharing station near the parking: a) P&R Bieżanów; b) P&R Kurdwanów; and c) P&R Czerwone Maki

Analysis of the use of the Wavelo system in Krakow indicates that the average time of renting a bike on the working days was 20 minutes, whereas the average travel distance with the use of a rental bike on the working days is 3.50 km. Thus, this system was used for short journeys and could be used to combine journeys with the use of means of public transport. The months of April, May, and June were characterized by the highest number of bike rentals. In January, February, March, November, and December, the number of bike rentals was the lowest, which was probably caused by the unfavorable weather conditions that occur in Poland in these months. The largest numbers of rentals and returns in the Wavelo system were between 15:00 and 19:00, whereas the least were from 11:00-15:00. It can be concluded that people used the bike-sharing Wavelo system in Krakow for recreational travel.

The calculated value of the equivalent distance from the analyzed P&R parking to the nearest bike-sharing stations indicates that despite the fact that the real distance from the P&R parking Bieżanów is the longest, the onerousness of pedestrian crossing is smaller than in the case of the other two parking lots, P&R Kurdwanów and P&R Czerwone Maki. The presented pedestrian access isochrones allow for the conclusion that in all analyzed parking, public transport stops are within 5 minutes of pedestrian access. The pedestrian access to the bike-sharing stations is greater in the city center than outside of it.

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