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SPATIAL ANALYSES AS SUPPORT FOR ROAD REAL ESTATE MANAGEMENT PROCESSES – CASE STUDY ON THE PAID PARKING ZONE IN KRAKOW

Abstract: The implementation of paid parking zones is one of the tools used to regulate parking policy in modern cities. This is primarily aimed at increasing vehicle turnover and encouraging residents to use alternative modes of transportation in their daily travels. The purpose of this study was to analyze the impact of extensions to Krakow's paid parking zone on traffic calming in its center, and to see if there is a chance to give back the downtown exclusively to pedestrians and micromobility users. The study was carried out in three stages, using GIS tools, including: an analysis of the widening of Krakow's paid parking zone, an assessment of the degree of traffic calming in the center based on a comparison of available environmental noise immission maps, and an analysis of the Park and Ride system as a tool to support the reduction of vehicular traffic in the city center, along with proposed directions for its development. The final results of this research are maps representing: an analysis of the surface changes of the paid parking zone, the difference in the level of noise immission in 2012 and 2017 in Krakow, as well as time and distance analyses made for existing and designed parking lots in the Park and Ride system.

Keywords: public roads, real estate management, legal status of real estate, paid parking zones, Krakow, GIS, spatial analysis

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Introduction

The continuous increase in the number of motor vehicles in cities, especially in metropolitan areas, directly affects the daily lives of their residents. This contributes to an increase in environmental pollution (mainly from car exhaust fumes and noise) and public irritation resulting from both the traffic jams created and the loss of commuting time. In addition, the increase in the number of cars translates into problems finding parking spaces, especially in city center areas, where strict development does not allow for the construction of new parking lots, either above ground or underground (Alam, 2012). If there is any talk of building new parking lots at all, it involves a lot of public resistance, as it usually comes at the expense of urban green spaces.

The purpose of the following study was to analyze the impact of extending the paid parking zone in Krakow on traffic calming in its center, and to see if there is a chance to give back the downtown exclusively to pedestrians and micromobility users through the development of the transportation network including the expansion of the park and ride system. This study will support the decision-making processes of local authorities related to the implementation of sustainable mobility in Krakow.

Background of the study

The issue is being widely debated at international, national as well as local levels. Decision-makers and space-planners are constantly looking for opportunities and tools to improve and smooth mobility within city boundaries. Sustainable urban development policies include measures to reduce the need to move around and provide favorable conditions for energy-efficient and environmentally friendly forms of transportation (Jabareen, 2006). At the same time, all measures are aimed at realizing the goals of sustainable development, which was first heard of as early as 1972 in Stockholm, and defined in detail in 1987 in the World Commission on Environment and Development Report “Our Common Future”. In the Report, sustainable development was presented as development that meets the needs of the present generation while not negatively impacting the ability of future generations to meet their needs. In addition, it noted the need to link three key areas: ecological (environmental), economic (business) and social (social justice) (Brundtland, 1987). Which means that economic development must be based on the principles of social justice and environmental protection (Płaciak, 2011), (Drosik et al., 2022; Ogryzek, 2022). The announcement of the report brought the concept of sustainability permanently into the language of politics, the economy, the media and academic discussions. As part of the continuing research on the development of the concept of sustainability in both Agenda 21 and Agenda 2030, special attention has been paid to the development of comprehensive policy and practical solutions to support the sustainable development of transportation, which is one of the main elements of sustainable development and a key topic in environmental debates devoted to the consideration of urban form (United Nations, 1993; United Nations, 2015).

Sustainable transportation development plays a fundamental role in addressing global challenges such as climate change, resource shortages and ensuring the equitable

access to mobility (Forum, 2021). Examples of measures to combat these calls include reducing pollutant emissions (including noise) by locating noise barriers in the form of walls (Szopińska et al., 2022), introducing restricted traffic zones, promoting public transportation, reducing the length and time of trips, and building sustainable transportation infrastructure – investing in green transportation systems (for example, park and ride) (Jabareen, 2006; Skrobacki, 2011).

It has been repeatedly cited in the literature that the implementation of the paid parking zones has calmed traffic in the urban center and contributed to an increase in the popularity of alternative forms of transportation, among others: public transportation, cycling or walking (Shoup, 2011; Barter, 2011; Gonzalez et al., 2022; Mackowski et al., 2015; Khan et al., 2020). Modern urban planning concepts, which include: Compact City, Smart City, Eco City, Green Urbanism or even Cittaslow also focus primarily on reducing the use of cars by residents in favor of pederastian mobility, cycling and the use of multimodal public transportation (Broniewicz, 2017). An example of a Smart City can be found in Rzeszow, where enacted local plans directly influence its development (Balawejder et al., 2021). In addition, Rzeszów has a paid parking zone (eRzeszów).

Pedestrian mobility, in cities implementing modern urban planning concepts, is a desirable form of transportation because it follows directly from the goals described in Agendas 21 and 2030 (United Nations, 1993; United Nations, 2015). This method of transportation depends on pedestrian accessibility that is, among other things, guaranteeing a safe and friendly environment in which sidewalks and paths are both comfortable and attractive. Telega, Telega and Bieda, in their article, proposed a new approach to measuring pedestrian accessibility, which is one of the many indicators necessary to achieve sustainable urban development (Telega et al., 2021). They measured accessibility based on density maps of specific urban functions and networks of publicly accessible sidewalks and paths.

What is more, increasing pedestrian comfort and improving traffic capacity in city centers can result from the introduction of restrictions such as paid parking zones and restricted traffic zones (Stangel, 2013), which are common tools for shaping space in terms of mobility and are one of the sources of income for the budget of local governments. As a result of their functioning, mandatory parking fees are imposed, in the areas covered by them, usually during designated hours and days of the week.

The first paid parking zones in Poland were established as early as the 1980s as a way for local authorities to cope with the constant increase in the number of motor vehicles while failing to expand road infrastructure, particularly in terms of parking spaces (Kącki & Duda-Wiertel, 2018). In the Polish legal system, in 1985, the Law on Public Roads (Law, 1985) for the first time addressed the possibility of charging for the use of public roads by certain users. In the current wording of this law, there is the concept of paid parking zone and downtown paid parking zone, whereby:

- Paid parking zone is established in areas characterized by a significant deficit of parking spaces, if this is justified by the needs of traffic organization, in order to increase the turnover of parked motor vehicles or to implement local transport

policy; in particular, to limit the availability of the area for motor vehicles or to introduce preferences for public transport;

- A downtown paid parking zone shall be established in areas of clustering of intensive development of the functional downtown, which is the actual center of the city or a district in a city with a population of more than 100,000 people, if the conditions which apply to the paid parking zone are met, however, its establishment alone may not be sufficient to implement local transport or environmental policies.

Krakow, besides these two space shaping tools, also uses a traffic management method called Park and Ride as part of its transportation policy. This is a system of parking lots that provide intermodal connection points between private vehicles and public transportation (Ortega et al., 2021). Transportation policy most often seeks to reduce transportation congestion, eliminate unnecessary urban migration and provide an optimal transportation system. It is based on a well-planned network of roads, modes of transport, parking system and logistics (Szumilas & Pach, 2017).

The above-mentioned elements implement the assumptions of sustainable transport development. Many cities are deciding, among other things, to introduce restricted traffic zones and parking fees in these zones, and to expand the Park and Ride system. Examples of foreign cities where paid parking zones operate can be: Prague (Praha), London (Litman, 2005), San Francisco (Maternini et al., 2017), Palermo (Migliore et al., 2014) or Uherské Hradiště (Růžička et al., 2019). On the other hand, examples of cities where an efficient park-and-ride system is in operation can be: London, Hong Kong (HKTD, 1995), Brussels (Li et al., 2024), New York (Holguín-Veras et al., 2012), Paris (Yin et al., 2023).

Research methodology and data

The analysis of the impact of extensions to the paid parking zone in Krakow, Poland's second largest and most populous city (Fig. 1), on traffic calming in its center and the examination of the possibility of excluding the center from vehicular traffic were carried out in the following stages: (IA) analyzing all surface changes of the paid parking zone in Krakow; (IB) checking the degree of traffic calming in the zone by analyzing the level of noise immission in the center; (II) analyzing the Park and Ride system as a tool to support the reduction of vehicular traffic in the city center, along with proposed directions for its development. A detailed scheme of the study is shown in Fig. 2.

Fig. 1. Location of the city of Krakow (red color) against the background of the Małopolska Voivodeship (blue color) and Poland (yellow color)
Source: own study

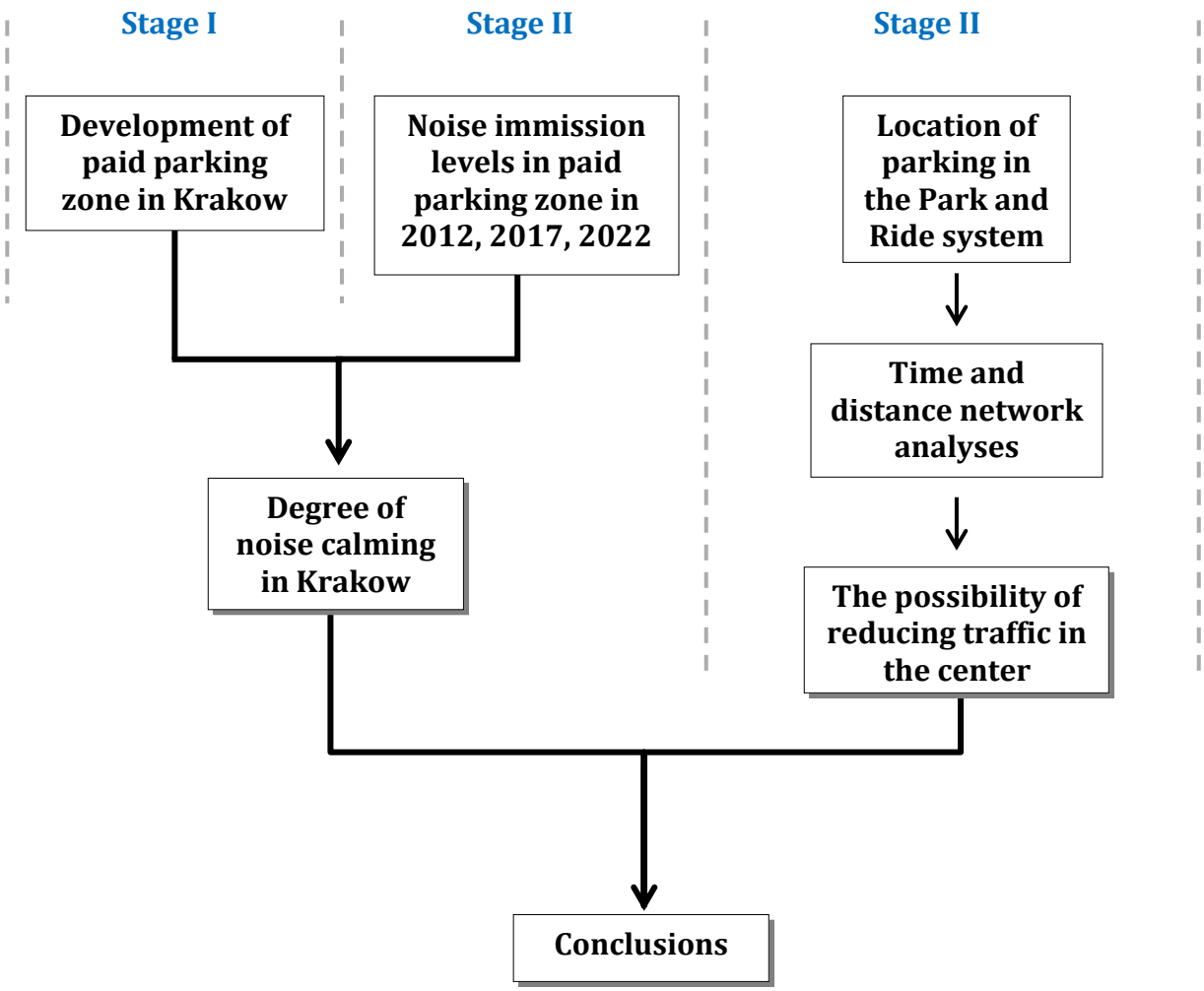

Fig. 2. Research scheme
Source: own study

The research was divided into two separate parts. The first included stages IA and IB, while the second was stage II. As part of Stage IA, all extensions of the paid parking zone were visualized, while as part of IB, the relative differences between the pixel values of the 2012 and 2017 noise immission maps (which were made using the same calculation method) were calculated. In the next step, the boundaries of the paid parking zones that were in effect in 2012, 2017 along with the current one were superimposed on the resulting map with the relative differences in the pixel values of the noise immission maps. This allowed us to visually analyze whether there is a correlation between the expansion of the paid parking zone and noise levels in the center. Part II of the study was a step that examined whether the expansion of Krakow's park-and-ride system could contribute to giving the center back to pedestrians, and thereby to calm traffic in the center. For this reason, analyses of the temporal and distance accessibility of Park and Ride parking facilities were carried out, developed for Krakow's network of bicycle paths and other bicycle-friendly infrastructure (including low-traffic roads).

The following were used to conduct the research:

- documents constituting acts of local law, obtained from the websites of the Public Information Bulletin of the Office of the City of Krakow (BIP) and the Official Journal of the Małopolskie Voivodship (DUWM, 2024) – the documents are publicly available and downloadable in pdf format;
- public spatial data released by the Municipal Spatial Information System of Krakow (MSIP) in terms of:
    - immission maps depicting the level of noise in the environment – expressed by the L_{DWN} index in the years: 2012, 2017, 2022;
    - location of the tramway network;
    - location of parking lots in the Park and Ride system;
- data obtained from the OpenStreetMap (OSM) open resource on the network of bicycle paths and other cycling-friendly infrastructure (including low-raffic roads).

Reviewing the world literature, it was found that GIS is a common tool used in the processing and analyzing of road noise maps. Ko, Chang and Lee's work focused on three-dimensional GIS analyses for noise mapping of building exterior elevations (Ko et al., 2011). Szopińska (2017) in an article presented the possibility of creating a theoretical model of road noise with the help of GIS. Puyana-Romero, Cueto, and Gey (2020), in their work, tested a 3D GIS tool for detecting high noise points on major roads. In contrast, Adza, Hursthouse, Miller, Boakye (2022) focused on using GIS for analyzing the combined relationship between noise and air pollution. The given studies present various methods of using GIS tools in the decision-making process for planned noise measures. In Krakow, thanks to conducting field surveys and then processing them, sound immission ranges were obtained, which in turn, using GIS software tools, were superimposed on a map of areas with specific types of development and permissible noise levels. The final result of these analyses are the output maps in the form of identification of noise-prone areas. (MSIP).

Taking the above into consideration, in the present work, all spatial analyses for the implementation of the study were carried out in ESRI's ArcGis Pro 3.3.0. software.

Results and discussion

Analysis of territorial changes of Krakow's paid parking zone

The history of the Krakow Paid Parking Zone goes back to the 1980s, when the National Council of the City of Krakow, through Resolution No. XXXVI/225/88 of April 6, 1988, decided to introduce a project aimed at calming wheel traffic in the city center (Kącki & Duda-Wiertel, 2018; Resolution, 1988). Analyzing all available resolutions on the public information bulletin (BIP) website since the 1980s, 32 zoning changes were counted, 7 of which were surface changes.

Using ESRI's ArcGis Pro tool, all surface changes to the paid parking zone were visualized, up to its planned expansion in 2026. The changes to the area are shown in Fig. 4 and 5. Finally, all the changes were superimposed (Fig. 4). The area of the zone adopted in 1988 was about 200 hectares, while the one currently in effect covers more than 2,000 hectares, which is 10 times larger than the original. Figures 3 and 4 show a summary statement of all the changes resulting from the adopted resolutions. Initially only the inner city was affected, while currently the zone has spilled over primarily into Krowodrza and Podgórze.

Figure 5 shows the planned expansion of the zone, which was originally scheduled to go into effect in August 2024, but due to ongoing litigation over the provisions of Resolution No. CIX/2952/23, it has been postponed by two years, ultimately to August 2026.

Analysis of immission maps showing the level of noise in the environment, expressed by the L_{DWN} index, in Krakow from the years: 2012, 2017, 2022

Noise is one of the most common dangers of civilization, having a direct impact on the quality of life and human health. Noise can be defined as any harmful, unpleasant, annoying sound occurring in a given place, time and circumstances. According to the Law on Environmental Protection, noise is understood as sounds with frequencies from 16 Hz to 16,000 Hz (Law, 2001). Analyzing the source and location of noise, several types of noise can be mentioned: industrial, traffic, municipal or residential. This study will analyze traffic noise, particularly of roads origin (Szopińska, 2015). The source of traffic noise is determined by summing the noise emissions from each vehicle involved in the traffic flow, namely: light motor vehicles, medium trucks, heavy trucks, two-wheelers (Directive, 2002).

In Krakow, strategic noise maps for 2012, 2017 and 2022 have been made available through the Municipal Spatial Information System (MSIP) Portal, following the adoption of Directive 2002/49/EC of the European Parliament and of the Council of June 25, 2002. This act introduced the obligation to prepare strategic noise maps, which are subject to analysis and revision as necessary, but at least every five years from the date of preparation (Directive, 2002).

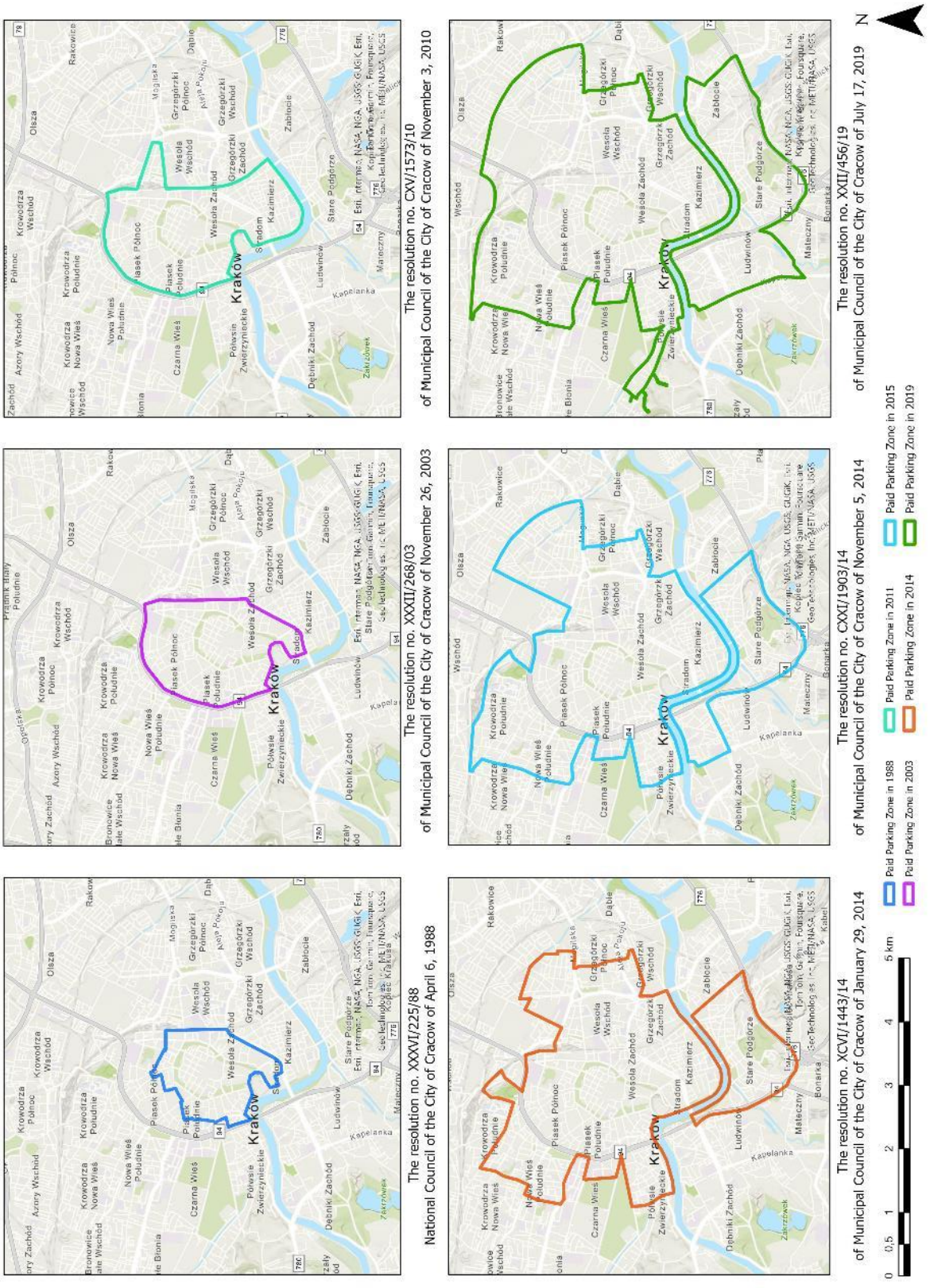

Fig. 3. Changes in the area of the paid parking zone in Krakow – part 1
Source: own study

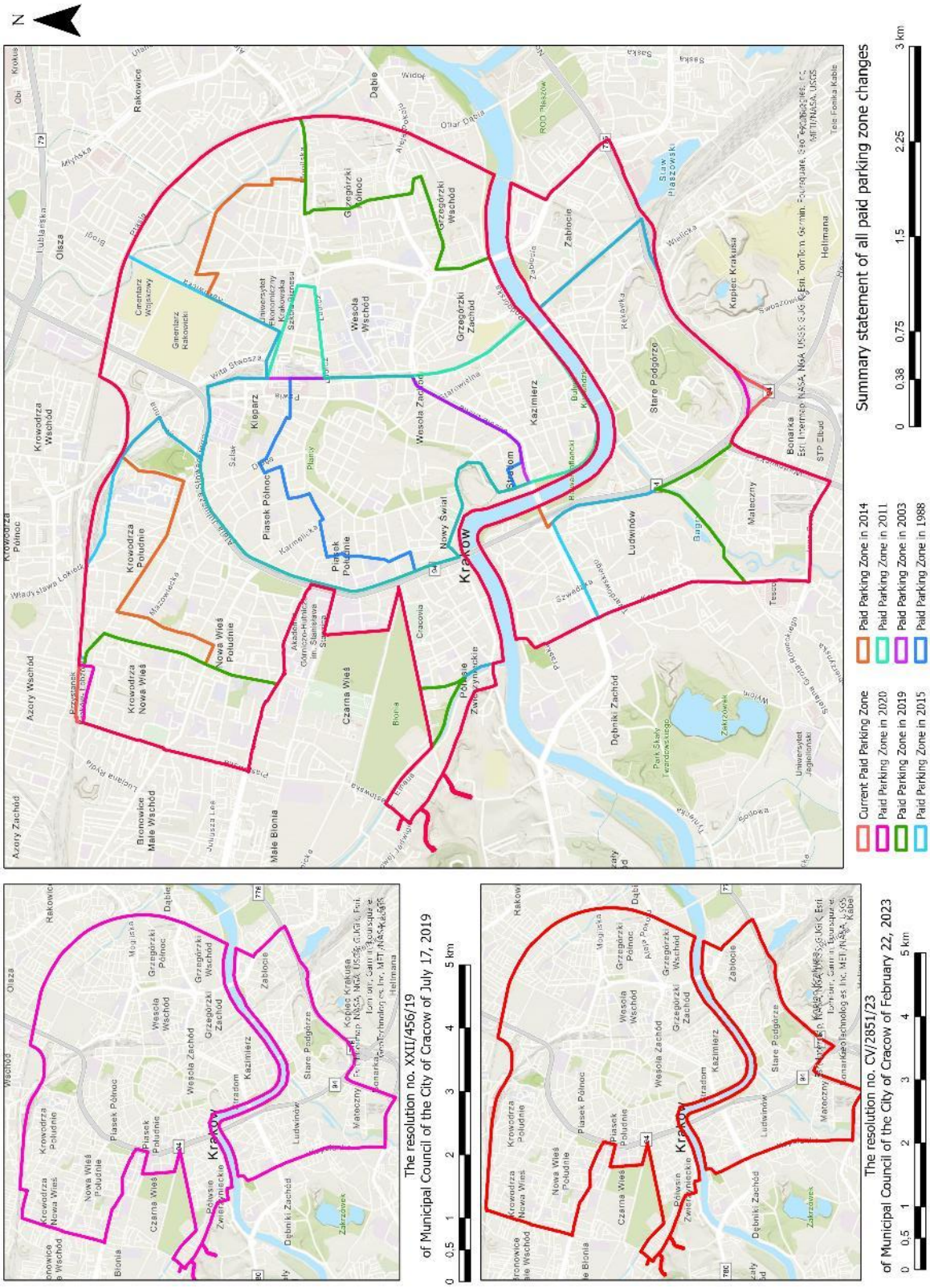

Fig. 4. Changes in the area of the paid parking zone in Krakow – part 2
Source: own study

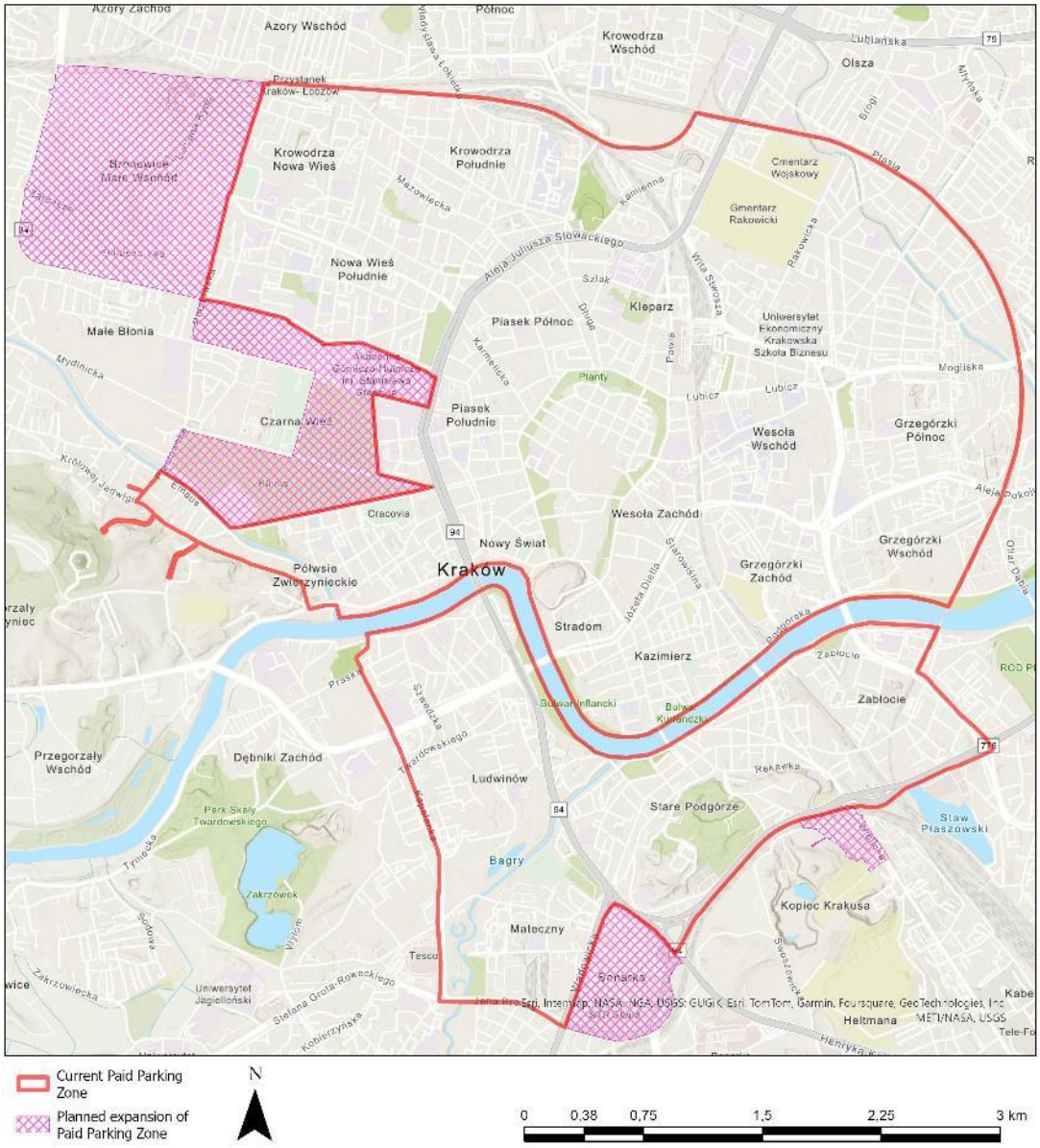

Fig. 5. Planned expansion of the paid parking zone postponed until August 2026
Source: own study

The immission maps presented illustrate the level of noise in the environment expressed by the L_{DWN} index, which is defined in the law as "the long-term average sound level A expressed in decibels (dB), determined in accordance with ISO 1996-2: 1987 during all days of the year (understood as a given calendar year with respect to sound emissions and an average year with respect to meteorological conditions), taking into account the time of day (understood as the time interval from hrs. 600 hrs. to 1800 hrs.), evening time (understood as the time interval from 1800 hrs. to 2200 hrs.) and night time (understood as the time interval from 2200 hrs. to 600 hrs.); this index is used to determine the overall noise annoyance" (Law, 2001). Currently in Poland, permissible levels of noise in the environment have been defined (Decree, 2007). For roads, the permissible long-term average sound level A in dB is presented in Table 1.

Table 1. Permissible long-term average sound level A in dB

No.	Type of land	**L_{DWN}** *(permissible long-term average sound level A in dB)* *Reference time interval equal to all days of the year*
1	a) Protective zone "A" of the resort	**50 dB**
	b) The areas of hospitals outside the city	
2	a) The areas of single-family residential development	**64 dB**
	b) The areas of buildings connected with permanent or temporary residence of children and young people	
	c) The areas of nursing homes	
	d) The areas of hospitals in cities	
3	a) The areas of multi-family housing and collective residence development	**68 dB**
	b) The areas of Homestead development	
	c) Recreational and leisure areas	
	d) Residential and commercial areas	
4	The areas in the city center zone of cities with more than 100,000 inhabitants	**70 dB**

Source: (Regulation, 2007)

Information obtained from the portal (MSIP) shows that the French noise calculation methodology, NMPB-Routes 96 (SETRA-CERTULCPCCSTB), was used for the 2012 and 2017 maps. In contrast, the development of the 2022 strategic noise maps used the European CNOSSOS-EU (Common Noise aSSessment MethOdS) method for all types of noise. The NMPB-Routes-96 method includes, among other things, determining the sound power level for each source (vehicle) and looking for sound propagation routes between each source and the point of reception (direct route, reflected and/or deflected route) (Kuboszek, 2017). The CNOSSOSEU method, on the other hand, was created to standardize across the European Union the methods of noise assessment performed within the framework of strategic noise maps (for cities with a population of more than 100,000, major roads, railroads and airports). This method is used to calculate long-term noise assessment indicators, taking into account the phenomena accompanying noise propagation in the environment, based on a model of noise emissions from various sources (Directive, 2002).

Figures 6 and 8 show immission maps depicting environmental noise levels, as expressed by the L_{DWN} index, in Krakow from the years: 2012, 2017, 2022. The maps were limited to the extent of the current paid parking zone (red), with a buffer of 1 km, to see if subsequent expansions of the zone affected noise transmission outside the zone. What's more, the maps for each year indicate in blue what area was in effect at that time. In addition, the network of public roads in the zone (gray) on which parking fees are charged has been imposed.

In order to check whether there was traffic calming in the zone, environmental noise immission maps expressed by the L_{DWN} index in Krakow from 2012 and 2017 were compared. The tools available in the GIS program ArcGIS Pro – "Compute Change Properties" raster analysis – were used. The above-mentioned noise immission maps

were compared using the relative difference method (difference in pixel values, taking into account the number of pixels compared between the two raster datasets). The results of the analysis are shown in Fig. 7.

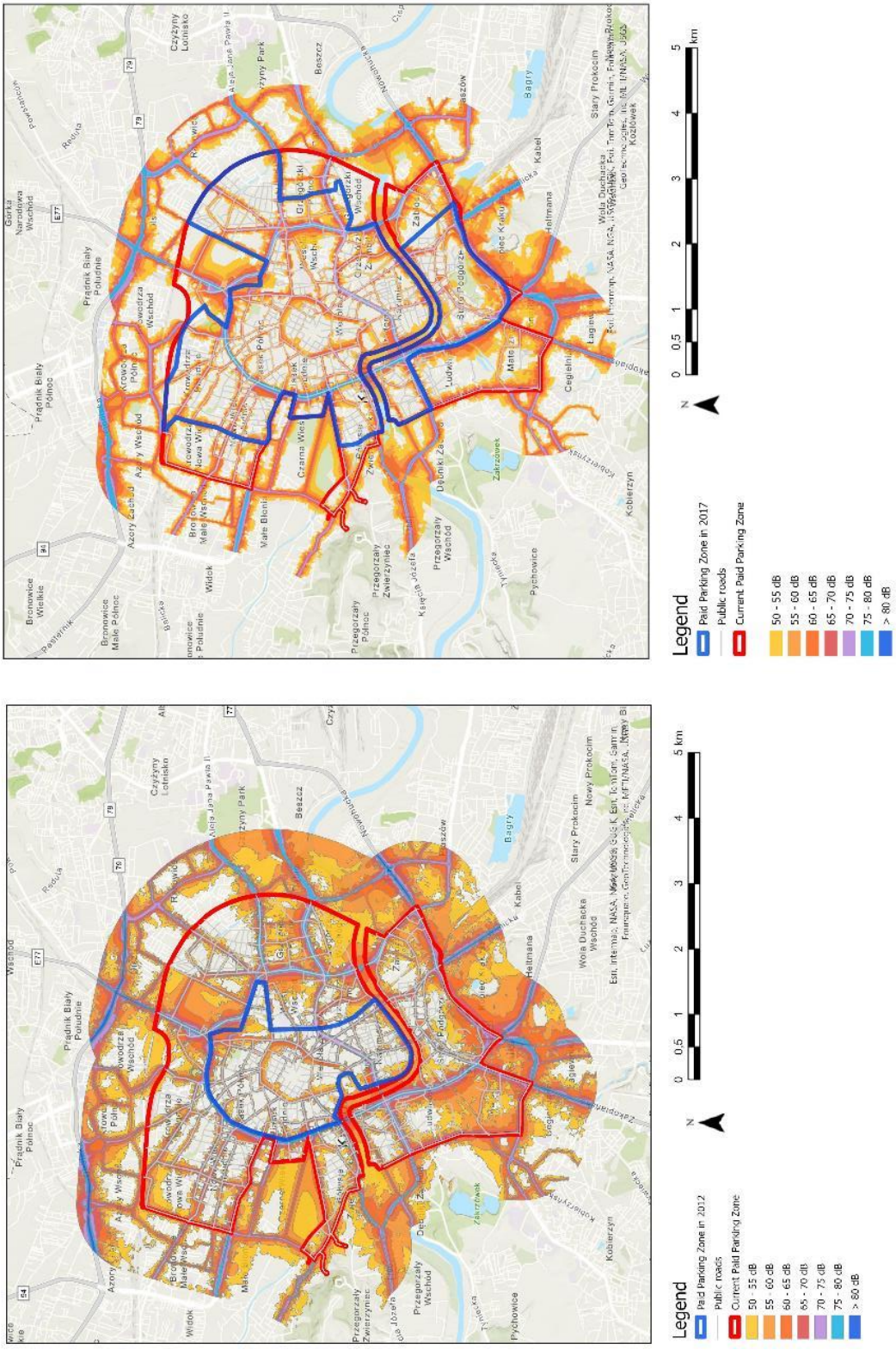

Fig. 6. Immission maps of environmental noise levels expressed by the L_{DWN} index in Krakow from the years 2012 and 2017
Source: own study

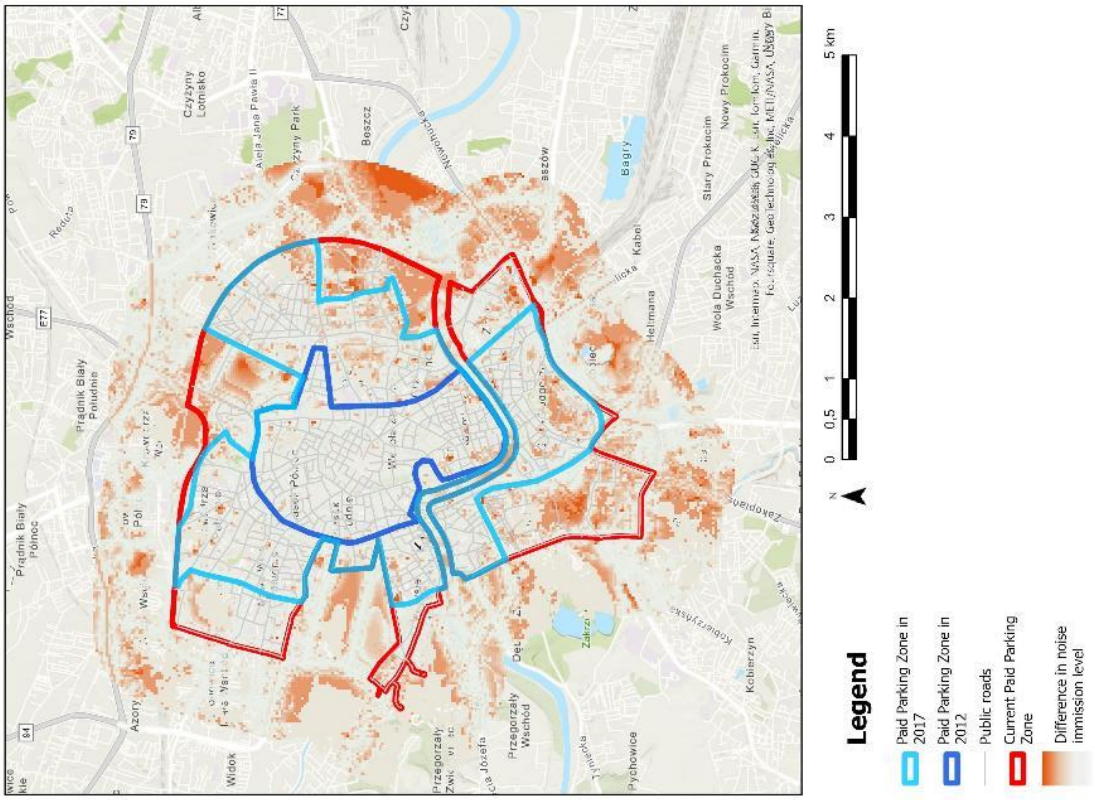

Fig. 7. Immission map showing the difference in environmental noise levels, expressed by the L_{DWN} index, in Krakow from 2012 and 2017
Source: own study

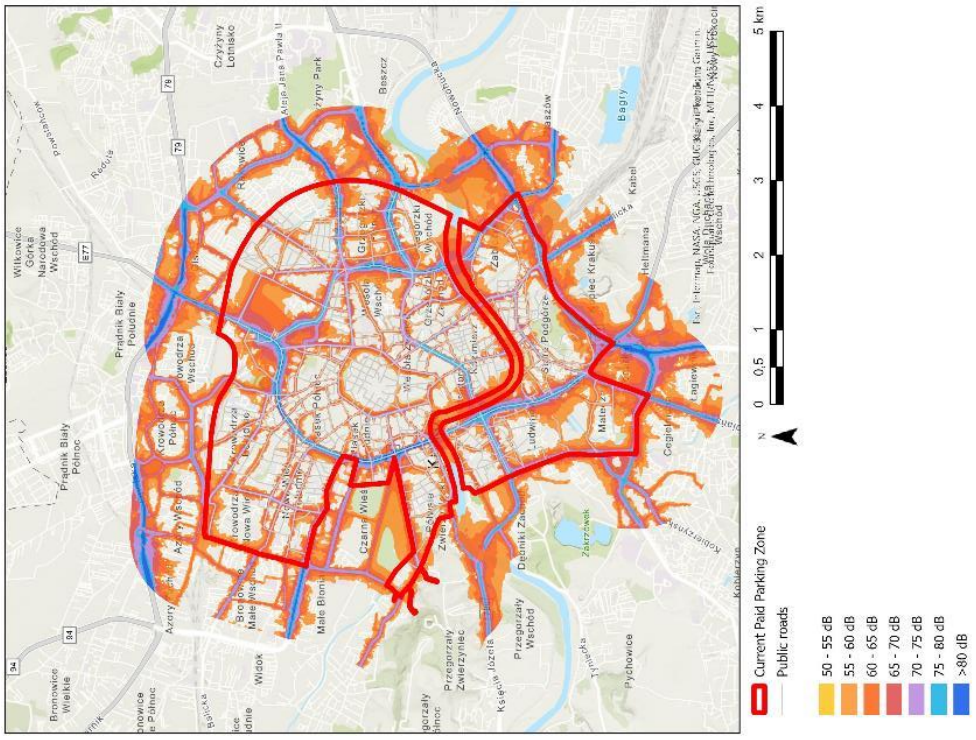

Fig. 8. Immission maps of environmental noise levels expressed by the L_{DWN} index in Krakow from the 2022
Source: own study

By analysing visually the map presented (Fig. 7), the first view gives the impression of a significant decrease in the level of noise immission against the current zone and outside its boundaries, but when this is referred only to the boundaries of the paid parking zones that were in force in 2012 and 2017, different conclusions can be drawn. In the inner city there is practically no change, this is due to the fact that the downtown zone has been in effect since 1985. The expansion of the zone in 2014 (in blue) contributed to a moderate decrease in noise levels in the southern and western parts of the zone. Relating the overall results of noise immission measurements to the acceptable long-term average sound level A in dB specified in the regulation, there is a significant exceedance. In the article "Noise Reduction by Urban Traffic Management", the authors highlighted that paid parking zones reduce the harmful effects associated with noise (Desarnaulds et al., 2004) which was confirmed in the present study as well.

Comparing the 2012 and 2017 maps with the 2022 study, in which the CNOSSOS-EU methodology was used to calculate noise levels, different noise ranges are observed, therefore such a comparison is not representative due to discrepancies in calculation assumptions.

Transportation network analysis, including network analysis of the timing and distance of the location of the parking lots in the Park and Ride system

Park and Ride system as a support for reducing city traffic

The main goal of the Park and Ride system is to improve the accessibility of city centers while reducing car traffic, which translates into a reduction in noise and air pollution in the city in particular (Szarata, 2005). The idea of this system comes down to leaving cars in specially prepared parking lots and then continuing the journey using public transportation (streetcars, buses, trains such as agglomeration high-speed rail) or also using a mode of transport such as bicycles or electric scooters. The main advantages of the Park and Ride system include:

- protecting the downtown from excessive parking demand;
- convenient location of parking lots, which means that they are located on the peripheries of cities near major roads and transportation nodes, enabling an increase in the share of trips made by multimodal public transportation;
- safety, ensured by the use of continuous monitoring of parking lots;
- travel time savings due to the lack of standing in traffic jams;
- saving money for P+R users, ensured by low and fixed parking fees in the form of a public transportation ticket;
- smoothing traffic flow in the city, reducing the number of cars= reducing traffic jams;
- reducing the need for transportation land for parking in city centers.

According to (Szarata, 2005), the main factors that influence traffic participants' using the P+R system are:

- inability to leave the car near the destination (parking bans, restricted traffic zones, congested city centers with limited parking spaces, where in addition there is very often a paid parking zone);
- concern about the safety of the car;

- overloading and congestion of streets leading to the city center;
- unfamiliarity with the city.

Nevertheless, it is worth bearing in mind that Park and Ride parking lots are not welcomed by residents where they are to be located due to the local increase in traffic, noise and pollution (Lester, 2013). Moreover, opponents believe that the construction of a parking lot will not solve the parking problem, and will additionally generate more traffic jams in the city (Szumilas & Pach, 2017). Another important issue raised by Kimpton, Pojoni and others in their work is awareness of the uncertainty of multimodality. Park and Ride lots can be overcrowded and a parking problem arises already at the entrance to the city. There may be delays or cancellations in rapid transit (rail) and also overcrowding, resulting in an inability to use this service. Thus, it may happen that the Park and Ride system not only does not shorten the travel time, but will make it even longer. This will translate into angry, frustrated and discouraged drivers to use this kind of solution (Kimpton et al., 2019). This issue is also addressed by Karamychev and Reeven, who note that multimodal travel can increase users' total travel time, including both time spent in the vehicle (e.g. waiting) and outside the vehicle (e.g. transfers), which can be a significant obstacle to daily commuting (Karamychev & Reeven, 2011).

Currently, according to information obtained from the Public Transport Authority of Krakow, there are 9 Park and Ride (P+R) system parking lots located in the north and south of the city, in the areas of existing tramway loops and important transfer nodes of the małopolska railroad (ZTP). The system is constantly being developed, and the newest parking lots that have just been put into operation are “P+R Pachońskiego” and “P+R Krowodrza Górka”. Figure 9 presents the approximate location of P+R parking lots against the background of the tramway network, along with the administrative boundaries of the city of Krakow and the current paid parking zone.

The Map shows an empty field in the area of the Nowa Huta district, where there are currently plans to build two more parking lots in this system: “Krakow Kościelniki” on Pysocice Street and “Krakow Przylasek” on Rzepakowa Street by Polskie Linie Kolejowe SA (PLK-SA).

First, using the “ArcGIS network analyst” extension, analyses were conducted on the time and distance availability of Park and Ride parking lots developed for the network of bicycle paths and other bicycle-friendly infrastructure (including low-traffic roads) in Krakow. Data on the location of Park and Ride parking lots was obtained from the server (MSIP), while data on the transportation network was downloaded from the portal (OSM). The temporal analysis of the “Service area” yielded three buffer zones around each P+R parking lot, which illustrate where bicycle access is possible: green within 5 minutes, yellow within 10 minutes and orange within 15 minutes. The results of the analysis are shown in Fig. 10.

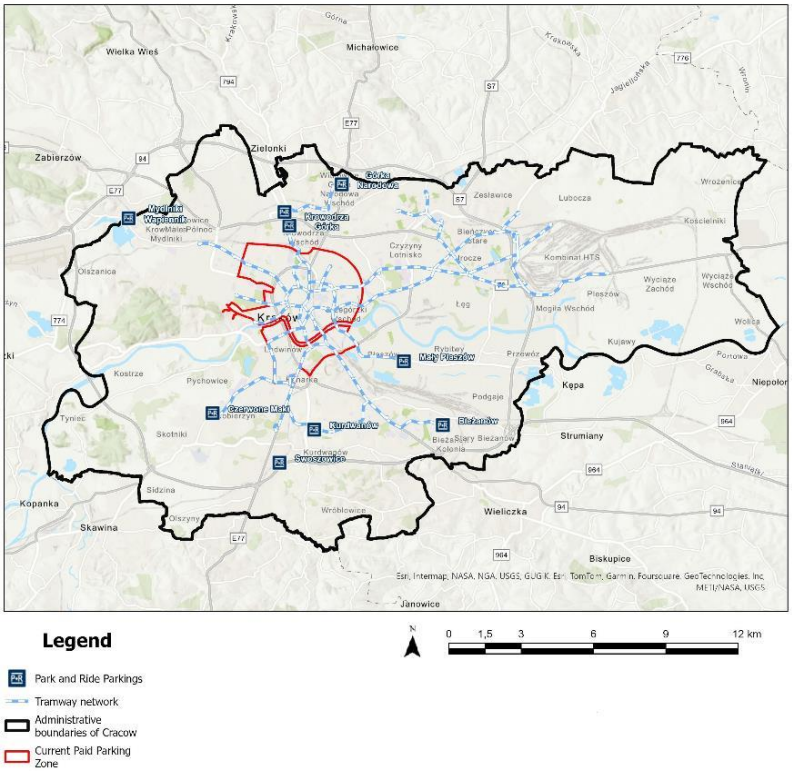

Fig. 9. Location of parking lots in the Park and Ride system along the tramway network, within the administrative borders of the city of Krakow
Source: own study

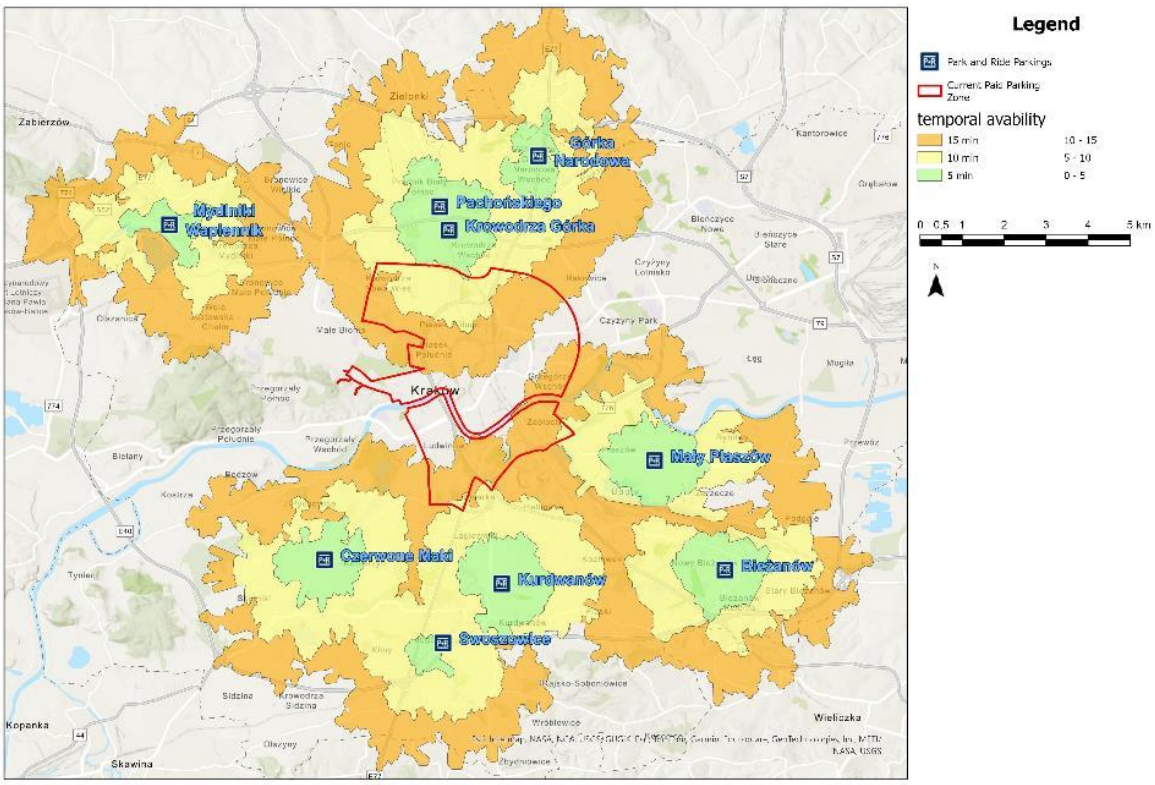

Fig. 10. Analysis of the temporal availability of the Park and Ride parking developed for the network of bicycle paths and other cycling-friendly infrastructure
Source: own study

In addition, using a tool to analyze the closest facility, Fig. 11 presents the shortest routes from P+R parking lots to the approximate boundaries of the paid parking zone.

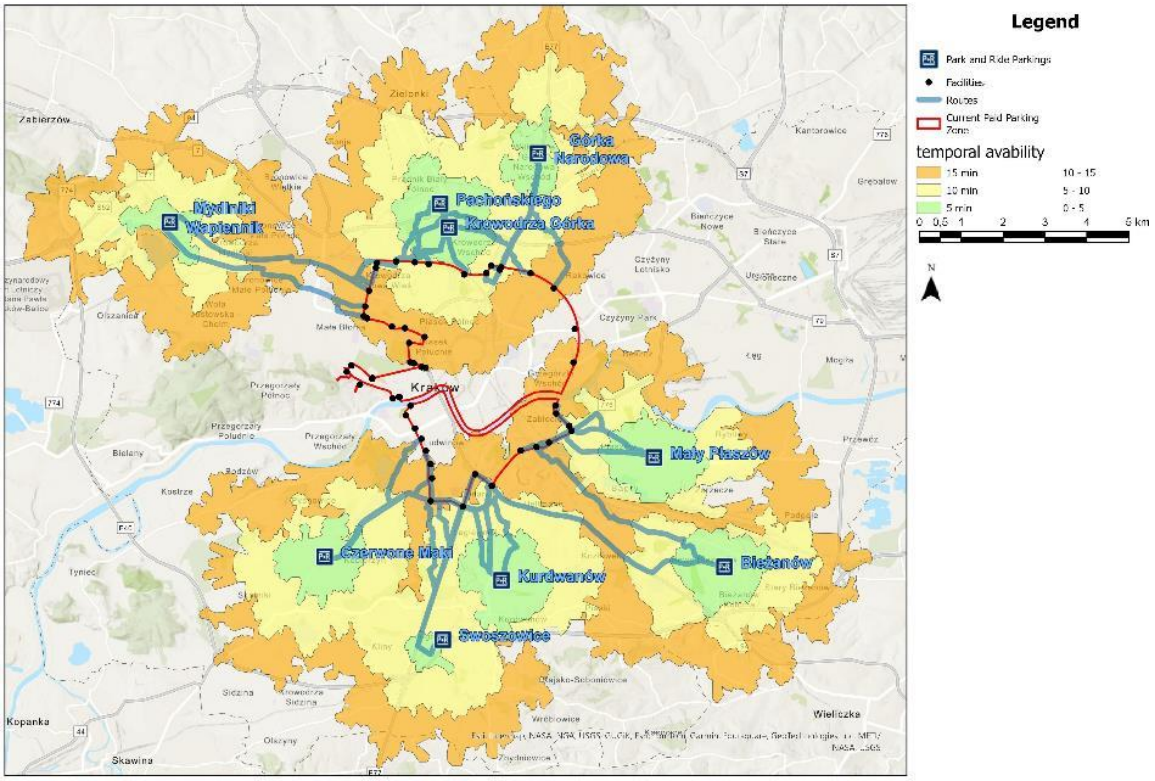

Fig. 11. Analysis the closest way from the Park and Ride parking to the boundaries of the Paid Parking Zone
Source: own study

The progress of Krakow in building P+R parking facilities is bringing positive results. Seven of the nine parking lots are located at tram loops, thus providing the opportunity to transfer and travel directly by tram to the city center, as well as reducing travel time. When parking a car in these particular parking lots, there are several ways to make parking payments. On a case-by-case basis, it is possible to collect a daily ticket, entitling you to multiple trips on all Krakow Public Transport vehicles. In addition, there is the possibility of making cyclical payments by submitting, for example, a monthly ticket of public transport (Ordinance, 2024). The other two parking lots, i.e. "P+R Mydlniki Wapiennik" and "P+R Swoszowice" are built in the direct neighborhood of the route of the Rapid Agglomeration Railway, which gives the possibility to change to trains of the Małopolska Railway and reach the city center. In this case, it is possible to use a metropolitan ticket that authorizes travel "on one ticket" by buses, streetcars and trains (Małopolska Railways).

Time analyses conducted in ArcGis Pro software have shown that from most P+R parking lots it is possible to reach the borders of the paid parking zone by bicycle within 15 minutes, which is a very good result. The location of Krakow's Park and Ride parking lots provides an opportunity to take advantage of bicycle mobility within the city of Krakow. Based on a network analysis of the closest distance, the shortest routes to be taken to get to the city center using, for example, city bicycles or electric scooters were

analyzed. Krakow has a park-e-bike program, available free of charge, at "P+R Czerwone Maki", "P+R Kurdwanów","P+R Mały Płaszów" and "P+R Nowy Bieżanów". This is a system of electric bicycles in the Krakow Functional Area as part of the Low Carb project "Capacity building for integrated low-carbon mobility planning in functional urban areas", co-financed under the "Interreg Central Europe 2014-2020" Program. In addition, there is a long-term bike rental service in Krakow, providing the opportunity to rent a bicycle for a period of one to three months (ZTP).

Maps indicate that Park and Ride parking lots are being built primarily in the north and south of Krakow, therefore this study has proposed 3 additional parking lot locations in the western part of the city: project 1, project 2 and project 3 – "Nowa Huta" area. The location of the parking lots was chosen analogously to the existing ones, which means, near the existing tram loops. In order to check whether these directions for the development of the Park and Ride system are appropriate, time and distance analyses were carried out for them, as for the currently used parking lots. The results of the analyses are shown in Figure 12 (against the background of the analyses performed for existing parking lots). The map shows an unavailable area – ArcelorMittal, which is an industrial company in Krakow, which was one of the largest steel producers in Poland (gray).

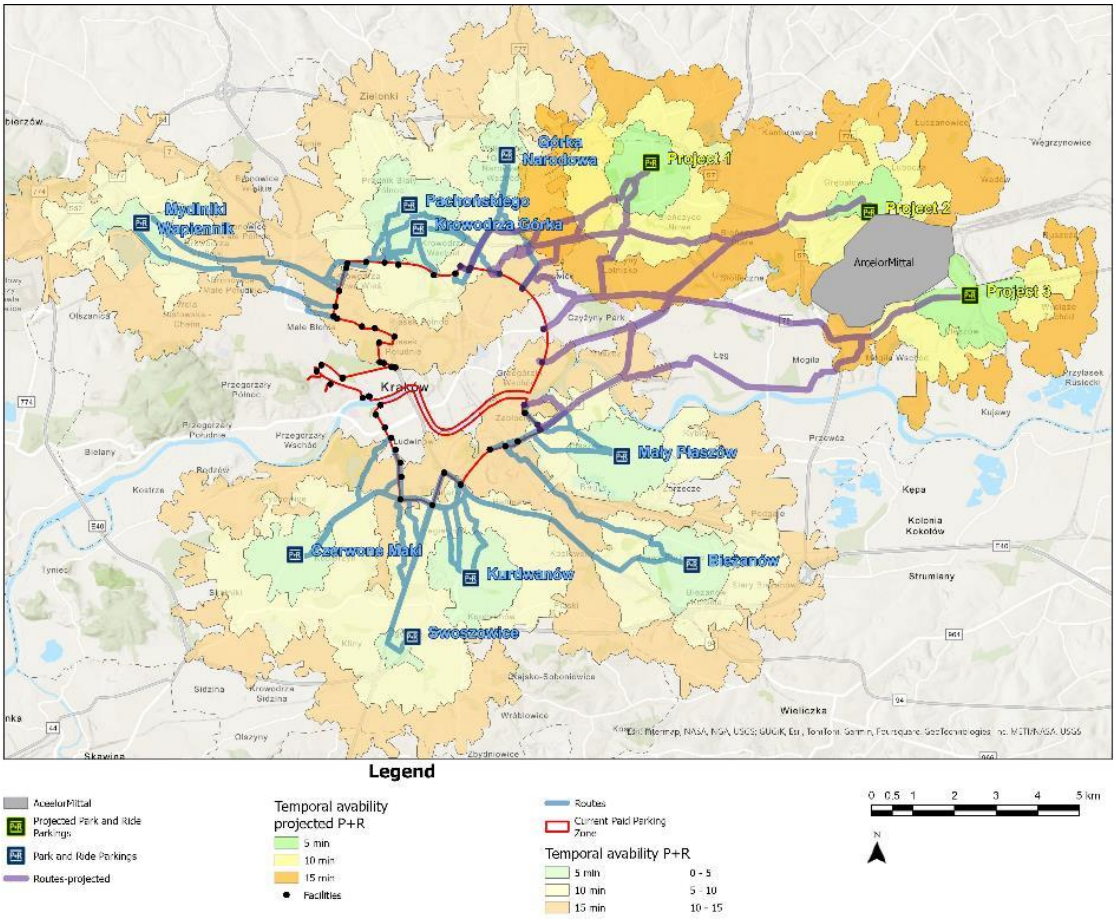

Fig. 12. Analysis of the temporal availability and closest way from the Park and Ride projected parking
Source: own study

The analysis showed that the best solution at the moment would be “project 1”, complementing the “Górka Narodowa” parking lot. On the other hand, “project 2” and “project 3” would be located too far from the center, not giving the possibility to reach the borders of the zone in up to 15 minutes. In their cases, it would be advisable to think closer to the location, and not, as in the case of the other parking lots in the area of tramway loops.

Conclusions

Transportation policy on mobility in paid parking zones in city centers is a key component of traffic and public space management, especially in the context of increasing urbanization and problems related to air pollution, noise and limited parking space. The topic is receiving increasing attention because cities around the world are trying to balance the needs of mobility with environmental protection and improving the quality of life for residents. The introduction of parking fees in paid parking zones contributes directly to increased turnover and parking availability, which is particularly important in congested urban areas. In addition, it encourages residents to use alternative means of transportation, such as public transportation, bicycles or walking – which fits perfectly with the tenets of modern urban planning concepts.

The article focuses on analyzing the impact of extensions to Krakow's paid parking zone on traffic calming in its center and the possibility of giving back its downtown exclusively to pedestrians and micromobility users. The research was conducted using GIS tools, which have allowed to conduct advanced spatial analyses. The following conclusions can be made based on the results of the study:

- Due to the different computational methodologies used in drawing up the noise immission maps (this refers to the differences in noise ranges between the 2012 and 2017 maps and the 2022 map), it is therefore difficult to assess the real impact of the zone expansions on traffic calming in the center. A general comparison of the 2012 with 2017 maps indicates noise reductions in the city of up to 75 dB, which could confirm that “the introduction of paid parking zones has calmed traffic in the city center”, nevertheless could also be due to other measures taken before the city's Decision-Makers. Examples include: road surface repairs and replacements, the introduction of restricted traffic zones, reducing traffic speeds, or locating residential buildings at an appropriate distance from traffic routes;
- Time and distance analyses have confirmed that the expansion of the Park and Ride system is desirable, as it offers a real opportunity to give the city center back to pedestrians and micromobility users. The location of parking lots along transportation networks such as tramways allows drivers to conveniently leave their cars on the periphery of the city and continue their travel to the center using public transportation, bicycles or other forms of micromobility. As a result, car traffic in central areas is reduced, which creates a more pedestrian-friendly space and environmentally friendly forms of transportation. However, it should be noted that the multimodal system is not perfect and there may be situations such as

overcrowded parking lots, delays in the operation of public transport, and this will translate into an increase in total travel time.

Taking the above into consideration, it is necessary to continue to study the noise level in Krakow. Noise immission maps, are made available every 5 years, so based on future data from 2025, it will be possible to assess the actual impact of traffic calming measures in the city center. In addition, it is necessary to consistently execute the established parking policy in Krakow, in particular to expand parking lots in the Park and Ride system, as this gives a real chance to make Krakow a green and zero-emission city.

As part of the current research, there is being developed a system to support the processes of managing real estate under transportation routes in terms of implementing modern urban planning concepts. It will contain spatial and descriptive data relevant to the introduction of sustainable mobility in Krakow, including the results of the research presented in this publication.

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References

Adza W.K., Hursthouse A.S., Miller J., Boakye D. (2023). Exploring the Joint Association of Road Traffic Noise and Air Quality with Hypertension Using QGIS. International journal of environmental research and public health, 20(3), 2238. https://doi.org/10.3390/ijerph20032238 [access: 26.07.2024].

Alam W. (2012). GIS based Assessment of Noise in Guwahati City of Assan, India. International Journal of Environmental Sciences, vol. 2, pp. 731–740.

Barter P. (2011). Parking Policy in Asian Cities. Asian Development Bank.

Balawejder M., Kolodiy P., Kuśnierz K., Sebzda J. (2021). Analysis of local spatial development plans for the smart city of Rzeszow (Poland). GIS Odyssey Journal, vol. 1, no. 1, pp. 147–162. https://doi.org/10.57599/gisoj.2021.1.1.147 [access: 26.07.2024].

BIP. https://www.bip.krakow.pl/ [access: 26.07.2024].

Broniewicz E. (2017). Gospodarowanie przestrzenią w warunkach rozwoju zrównoważonego (*Space management in the conditions of sustainable development*). Oficyna Wydawnicza Politechniki Białostockiej, Białystok.

Brundtland G.H. (1987). Our Common Future: Report of the World Commission on Environment and Development. Geneva, UN-Dokument A/42/427. http://www.un-documents.net/ocf-ov.htm [access: 26.07.2024].

Damidavičius J., Burinskienė M., Antuchevičienė J. (2020). Assessing Sustainable Mobility Measures Applying Multicriteria Decision Making Methods. Sustainability, 12(15):6067. https://doi.org/10.3390/su12156067 [access: 26.07.2024].

De Kluijver H., & Stoter J. (2003). Noise mapping and GIS: optimising quality and efficiency of noise effect studies. Computers, environment and urban systems, 27(1), pp. 85–102.

Desarnaulds V., Monay G., Carvalho A. (2004). Noise reduction by urban traffic management. Proceedings Ica.

Drosik A., Heidrich D., Ratajczak M. (2022). Wprowadzenie do zrównoważonego rozwoju (*Introduction to sustainability*). Podręcznik akademicki. Warszawa: Wydawnictwo Naukowe Scholar.

Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. OJ L 189, 18.7.2002, pp. 12–25.

DUWM. https://edziennik.malopolska.uw.gov.pl/actbymonths [access: 26.07.2024].

eRzeszów.https://www.erzeszow.pl/511-transport-i-komunikacja/6924-strefaplatnego-parkowania.html [access: 26.07.2024].

Gonzalez J., Gomez J., Vassallo J.M. (2022). Do urban parking restrictions and Low Emission Zones encourage a greener mobility? Transportation Research Part D: Transport and Environment. 107(4):103319. DOI:10.1016/j.trd.2022.103319.

Hong Kong Transport Department (HKTD) (1995). Parking Demand Study Final Report Hong Kong SAR Government.

ITF (2021). The innovative mobility landscape: The case of mobility as a service. International Transport Forum Policy Papers, no. 92, OECD Publishing, Paris. https://doi.org/10.1787/46903a00-en [access: 26.07.2024].

Jabareen Y. (2006). Sustainable Urban Forms. Journal of Planning Education and Research, vol. 26, no. 1, pp. 38–52. DOI: 10.1177/0739456X05285119.

Karamychev V., Reeven P. (2011). Park-and-ride: Good for the city, good for the region? Regional Science and Urban Economics, 41(5), pp. 455–464. DOI: 10.1016/j.regsciurbeco.2011.03.002.

Kącki P., Duda-Wiertel U. (2018). Zmiany terytorialne strefy płatnego parkowania w Krakowie w latach1988–2018. Transport Miejski i Regionalny, 37, pp. 13–18.

Khan A., Kulkarni P.G., Shergold I., Jones M., Dogramadzi M., Carnelli P.E., Sooriyabandara M. (2020). Reducing Parking Space Search Time and Environmental Impacts: A Technology Driven Smart Parking Case Study. IEEE Technology and Society Magazine, 39, pp. 62–75.

Kimpton A., Pojani D., Sipe N., Corcoran J. (2019). Parking Behavior: Park 'n' Ride (PnR) to encourage multimodalism in Brisbane. Land Use Policy. DOI: 10.1016/j.landusepol.2019.104304.

Ko J.H., Chang S.I., Lee B.C. (2011). Noise impact assessment by utilizing noise map and GIS: A case study in the city of Chungju, Republic of Korea. Applied Acoustics, 72(8), pp. 544–550. https://doi.org/10.1016/j.apacoust.2010.09.002. https://www.sciencedirect.com/science/article/pii/S0003682X10001945 [access: 26.07.2024].

Kuboszek A. (2017). Ocena poprawności metod symulacji komputerowej w badaniach hałasu komunikacyjnego. Systemy Wspomagania w Inżynierii Produkcji, vol. 6, no. 1, pp. 106–121.

Law on Public Roads dated March 21, 1985. Journal of Laws 1985, no. 14, item 60, as amended.

Law of Environmental Protection dated April 27, 2001. Journal of Laws 2001, no. 62, item 627, as amended.

Lester N. (2013). Park and ride in the UK. Zeszyty Naukowo-Techniczne Stowarzyszenia Inżynierów i Techników Komunikacji w Krakowie. Seria: Materiały Konferencyjne. 1(100), pp. 145–158.

Li J., Rombaut E., Vanhaverbeke L. (2024). How far are we towards sustainable Carfree cities combining shared autonomous vehicles with park-and-ride: An agent-based simulation assessment for Brussels. Computers, Environment and Urban Systems, 112. https://doi.org/10.1016/j.compenvurbsys.2024.102148 [access: 26.07.2024].

Litman T. (2005). London Congestion Pricing – Implications for Other Cities. CESifo DICE Report, vol. 3, no. 3, pp. 17–21.

Mackowski D., Bai Y., Ouyang Y. (2015). Parking Space Management via Dynamic Performance-based Pricing. Transportation Research Procedia, 7, 170–191. https://doi.org/10.1016/j.trpro.2015.06.010 [access: 26.07.2024].

Małopolska railroad. https://kolejemalopolskie.com.pl/ [access: 26.07.2024].

Maternini G., Ferrari F., Guga, A. (2017). Application of variable parking pricing techniques to innovate parking strategies. The case study of Brescia. Case Studies on Transport Policy, vol. 5, no. 2, pp. 425–437. DOI:10.1016/j.cstp.2017.03.010.

Migliore M., Lo Burgio A., Di Giovanna M. (2014). Parking Pricing for a Sustainable Transport System. Transportation Research Procedia, vol. 3, pp. 403–412. DOI:10.1016/j.trpro.2014.10.021.

MSIP. https://msip.um.krakow.pl/ [access: 26.07.2024].

New Urbanism Congress. Strategic Plan 2020. https://www.cnu.org/sites/default/files/StrategicPlan_2020.pdf [access: 26.07.2024].

Ogryzek M. (2022). The Sustainable Development Paradigm. Geomatics and Environmental Engineering, 17(1), 5–18. https://doi.org/10.7494/geom.2023.17.1.5 [access: 26.07.2024].

Ortega J., Tóth J., Péter T. (2021). Planning a Park and Ride System: A Literature Review. Future Transportation, 1, pp. 82–98. DOI: 10.3390/futuretransp1010006.

OSM. https://www.openstreetmap.org/#map=6/52.018/19.137 [access: 26.07.2024].

PLK-SA. https://www.plk-sa.pl/ [access: 26.07.2024].

Płaciak A. (2011). The Origin of Sustainable Development Idea. Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu. Ekonomia, vol. 17, no. 214, pp. 231–248.

Praha. https://www.praha1.cz/doprava-parkovani-a-uklid/zona-placeneho-stani/ [access: 26.07.2024].

Puyana-Romero V., Cueto J.L., Gey R. (2020). A 3D GIS tool for the detection of noise hot-spots from major roads. Transportation Research Part D: Transport and Environment, 84. https://doi.org/10.1016/J.TRD.2020.102376 [access: 26.07.2024].

Regulation of the Minister of Environment of June 14, 2007 on permissible noise levels in the environment. Dz. U. 2007, no. 120, item 826, as amended.

Resolution no. XXXVI/225/88 of the National Council of the City of Krakow dated April 6, 1988 on the project of "traffic calming in downtown Krakow".

Resolution no. XXXII/268/03 of the Krakow City Council of November 26, 2003 on fees for parking motor vehicles on public roads in Krakow, in the paid parking zone. Official Journal of the Małopolska Voivodeship no. 2003.400.4229.

Resolution no. CXV/1573/10 of the Krakow City Council of November 3, 2010 on amending Resolution no. XXXII/268/03 of the Krakow City Council of November 26, 2003 on fees for parking motor vehicles on public roads in Krakow, in the paid parking zone. Official Journal of the Małopolska Voivodeship no. 2010.616.4934.

Resolution no. CXV/1599/10 of the Krakow City Council of November 3, 2010 on directions for the Mayor of the City of Krakow.

Resolution no. XCVI/1443/14 of the Krakow City Council of January 29, 2014 on amending Resolution No. XXI/229/11 of the Krakow City Council of July 6, 2011 on establishing a paid parking zone, determining fees for parking vehicles on public roads in the paid parking zone, introducing a subscription fee for certain road users and the manner of collecting these fees. Official Journal of the Małopolska Voivodeship no. 2014.566.

Resolution no. CXXI/1903/14 of the Krakow City Council of November 5, 2014 on amending Resolution No. XXI/229/11 of the Krakow City Council of July 6, 2011 on establishing a paid parking zone, setting fees for parking vehicles on public roads in the paid parking zone, introducing a subscription fee for certain road users and the method of collecting these fees. Official Journal of the Małopolska Voivodeship No. 2014.6520.

Resolution no. XXII/456/19 of the Krakow City Council of July 17, 2019 on amending Resolution no. LXXXIX/2177/17 of the Krakow City Council of November 22, 2017 on establishing a paid parking zone, determining fees for parking of motor vehicles on public roads in the paid parking zone, introducing a subscription fee for certain road users and the manner of collecting these fees. Official Journal of the Małopolska Voivodeship no. 2019.5636.

Resolution no. CIX/2952/23 of the Council of the City of Krakow dated April 26, 2023 on amending Resolution no. CV/2851/23 of the Council of the City of Krakow dated February 22, 2023 amending Resolution no. LXXXIX/2177/17 on establishing a paid parking zone, establishing fees for parking vehicles on public roads in the paid parking zone, introducing subscription fees for certain road users and the manner of collecting these fees. Official Journal of the Małopolska Voivodeship no. 2023.3514.

Resolution no. VII/104/24 of the City Council of Krakow dated July 3, 2024. Amending resolutions: no. LXXXIX/2177/17 on establishing a paid parking zone, establishing fees for parking of motor vehicles on public roads in the paid parking zone, introducing a subscription fee for certain road users and the manner of collecting these fees; No. CV/2851/23 amending Resolution no. LXXXIX/2177/17 on establishing the paid parking zone, establishing fees for parking of motor vehicles on

public roads in the paid parking zone, introducing subscription fee for certain road users and the manner of collecting these fees; and no. CIX/2952/23 amending Resolution no. CV/2851/23 of the Krakow City Council of February 22, 2023, amending Resolution no. LXXXIX/2177/17 on establishing a paid parking zone, setting fees for parking vehicles on public roads in the paid parking zone, introducing a subscription fee for certain road users and the manner of collecting these fees. Official Journal of the Małopolska Voivodeship no. 2024.4781.

Růžička J., Navrátilová K., Tichý T. (2019). Respecting the parking rules in city centres. 2019 Smart City Symposium Prague (SCSP), pp. 1–6. DOI:10.1109/SCSP.2019.8805688.

Shoup D. (2011). The High Cost of Free Parking, Updated Edition. Routledge. SSRN Electronic Journal, United States.

Skrobacki Z. (2011). Od ogólnej idei zrównoważonego rozwoju do zasad zrównoważonego rozwoju transportu. Autobusy: technika, eksploatacja, systemy transportowe (*From the general idea of sustainable development to the principles of sustainable transport development. Buses: technology, operation, transport systems*), vol. 12, pp. 297–307.

Speck J. (2013). Walkable city: How downtown can save America, one step at a time. macmillan. Documents d'anàlisi geogràfica, 61(2), pp. 436–437.

Stangel M. (2013). Kształtowanie współczesnych obszarów miejskich w kontekście zrównoważonego rozwoju. Wydawnictwo Politechniki Śląskiej, Gliwice.

Szarata A. (2005) Ocena efektywności funkcjonalnej parkingów przesiadkowych (P+R). Politechnika Krakowska.

Szopińska K. (2015). Hałas drogowy jako czynnik wpływający na atrakcyjność miejskich terenów rekreacyjno-wypoczynkowych. Logistyka, pp. 4740–4749.

Szopińska K. (2017). Creation of Theoretical road traffic noise model with the help of GIS. Environmental Engineering 10th International Conference. Vilnius Gediminas Technical University, Department of Construction Economics & Property, vol. 10, pp. 1–8.

Szopińska K., Balawejder M., Warchoł A. (2022). National legal regulations and location of noise barriers along the Polish highway. Transportation Research Part D: Transport and Environment, vol. 109, 103359.

Szumilas A., Pach P. (2017). Review of Parking Policies in the Case of Medium-sized Polish Cities. Procedia Engineering, vol. 192, pp. 863–868. https://doi.org/10.1016/j.proeng.2017.06.149 [access: 26.07.2024].

Telega A., Telega I., Bieda A. (2021). Measuring Walkability with GIS – Methods Overview and New Approach Proposal. Sustainability, 13(4):1883. https://doi.org/10.3390/su13041883 [access: 26.07.2024].

Yin B., Oumar Diallo A., Seregina T., Coulombel N., Liu L. (2023). Evaluation of Low-Traffic Neighborhoods and Scale Effects: The Paris Case Study. Transportation Research Record, 2678(2), pp. 88–101. DOI:10.1177/03611981231170130.

ZTP. https://ztp.krakow.pl/ [access: 26.07.2024].