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Changes In the Intensity of Urban Traffic Based on the Occupancy Of P&R Car Parks: A Research in Krakow, Poland*

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Abstract

The policy of the European Union focuses on rationalizing the individual use of cars and improving the quality of urban public transport. Shaping the transport system in urbanized areas requires exerting various kinds of impact on the mobility of the resi-dents. In order to improve transport accessibility and help integrate innovative car park management solutions, Sustainable Urban Mobility Plans are being introduced. They are aimed at improving the mobility and quality of life of residents and tourists. The subject of the analyses undertaken were all P&R car parks operating in a closed system in Krakow. The aim of the research was to determine the importance of P&R in urban transport policy, the principles of this system's functioning and trends in daily, weekly and monthly occupancy in 2022-2024. P&R facilities are very important with regard to enabling the so-called Clean Transportation Zones to function.
The analysis was based on extensive unpublished statistical data from “vehicle history reports” obtained from the former company Municipal Infrastructure LLC (Miejska Infrastruktura Sp. z o.o.) and the Public Transport Authority in Krakow. The analysis used a varie-ty of basic statistical methods using SAS OnDemand for Academics and Statistica 13.3 software. The increasing interest taken in P&R was reduced due to the Covid 19 pandemic, but presently there appears a renewed increase in car park occupancy. The occupancy rate depends on the location of car parks. There is a very high demand for further investments of this type. At all P&R facilities, one can observe rhythmicity resulting from the holiday period and the function of Krakow as an academic centre, as well as rhythmicity in the circadian rhythm and weekly rhythm.

Keywords: sustainable transport; parking P&R; urban transport, Sustainable Urban Mobility Plans, urban mobility

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Introduction

The policy of the European Union focuses on rationalizing the individual use of cars and improving the quality of urban public transport. Very rapid development of individual motorization, with the slow expansion of road and parking infrastructure, especially in cities, means that the availability of these areas for users of passenger cars is increasingly limited.

The issue of sustainable mobility in urban transport policy is undertaken in many re-search works (by, among others, Skinner, Fergusson 1999; Banister, 2005; Molecki, Senkiel 2005; Kalisiak-Mędelska 2017; Zhenyu, Qifeng, Wei, Lihui, Fei, 2017; Korneć 2018; BielińskaDusza, Hamerska, Żak, 2021, Beim, 2021; Lower, Szumilas, 2021; Beim, Mazur, Pistelok

2023; Szagała, Brzeziński, Dybicz, Olszewski, Osińska, 2024; Ding, Manville, 2025; Rietveld, Stough 2025). Krakow's transport policy also postulates the creation of conditions for more efficient and safer road transport, while meeting the requirements of limiting its burden on the environment. These measures are intended to improve transport accessibility within the city itself and the city's accessibility from the areas of the metropolitan area, voivodeship (province) and the country (Szarata 2005; Bździuch, Bogacki 2017, Płaziak, Szymańska 2019; BorowiecGabryś 2021). One of the actions undertaken to improve Krakow's transport accessibility for car us-ers was the Park4SUMP project. It aims to help the city's municipal authorities integrate in-novative car park management solutions into a Sustainable Urban Mobility Plan (SUMP), which is supposed to improve the mobility and quality of life of the residents and tourists. The aim of the project was also the cooperation of partner cities from 14 countries in various measures intended to stimulate innovation in car park management and creating a more strategic and holistic transport policy as well as dissemination of the results of research conducted in the field of urban transport. Increase public awareness of pro-ecological solutions for transport was also an important assumption.

Shaping the transport system in heavily urbanized areas requires exerting various kinds of impact on the mobility of residents. An expression of this is also the estab-lished Clean Transport Zone, which, despite numerous protests from residents and local governments of municipalities in the Krakow Metropolitan Area, began to operate in June 2025. One of the instruments of such a policy should also be a system of trans-fer car parks, called “Park and Ride” (P&R or P+R). The principles of the European Union's transport policy perceive this system as a beneficial, alternative way of using passenger cars, implementing the postulate of multimodality and fostering the sustainable development of the city's transport system (Kar et al. 2023). At the same time, when coor-dinating urban transport, information on its intensity in a given time interval (daily, weekly and annual) is much needed (Singh et al. 2023). On account of the costs of such studies, they are not ordered on a continuous basis (except for cycling traffic in the city) (Dorocki 2022a).

In the light of the above premises, a question arises: what is the significance of P&R car parks in the transport system of Krakow and what are the principles of their functionng? The research analysis was carried out on the basis of the number of vehicles using parking spaces on a daily, weekly and monthly basis in the years 2022 to 2024 in four car parks: Czerwone

Maki, Kurdwanów, Bieżanów and Mały Płaszów.

The aim of the research was to answer the following questions:

- Is the time trend of car park occupancy during the period under study the same for all surveyed car parks?
- What is the annual and weekly trend in the volume of car traffic in Krakow based on the number of cars using the car parks surveyed?
- What is the pattern and trend of changes in the distribution of daily occupancy for individual car parks?

The subject of the analyses were all P&R car parks operating in a closed system in Krakow up to 2025, namely Czerwone Maki, Kurdwanów, Bieżanów and Mały Płaszów. The analysis was based on raw unpublished statistical data from hourly “vehicle history reports” obtained from the former company Miejska Infrastruktura Sp. z o.o. and the Public Transport Authority in Krakow, which were processed for the purposes of this work. The analysis used basic statistical methods using SAS OnDemand for Academics and Statistica 13.3 software. As a result of the research conducted, regularities in the occupancy of parking spaces on a daily, monthly and annual basis were

determined, taking into account the impact of the pandemic on the use of car parks. The article presents the initial results of the expected broader research in this area.

Currently, 9 P&R car parks function in Krakow and have 1,550 parking spaces, with only four car parks offering as many as 640 parking spaces in a closed system until March 2025 (Fig. 1). These four car parks are located in the southern and south-eastern part of the city. The northern part of the city was devoid of this type of car park until the creation of three P&R facilities in 2025 as part of the new tram line from Krowodrza Górka to Górka Narodowa. The parking facilities are located at the created Krowodrza Górka loop, in Pachońskiego street, at Górka Narodowa loop (670 parking places in total). Car parks operating in a closed system are equipped with devices of the Ticket Control System and the Toll Collection System cooperating in conjunction with it (entry and exit barriers).

In order to enter a car park, a valid magnetic card must be placed next to the reader, a QR code generated in a mobile application must be scanned, or a ticket must be collected. Users entering a car park by collecting a parking ticket are required to pay the applicable fee, in accordance with the car park tariff, before leaving the car park area. Parking free of charge is possible for the holders of the following cards: Krakowska Karta Miejska (KKM Krakowska Karta Miejska)/ Krakow Card (KK Karta Krakowska); Małopolska Agglomeration Card (MKA Małopolska Karta Aglomeracyjna); Electronic Student ID (ELS Elektroniczna Legitymacja

Studencka); Electronic Doctoral ID Card (ELD Elektroniczna Legitymacja Doktorancka); Krakow Family Card 3+ (Krakowska Karta Rodzinna 3+) and Krakow for the family “N” (Krakow dla rodziny „N”).

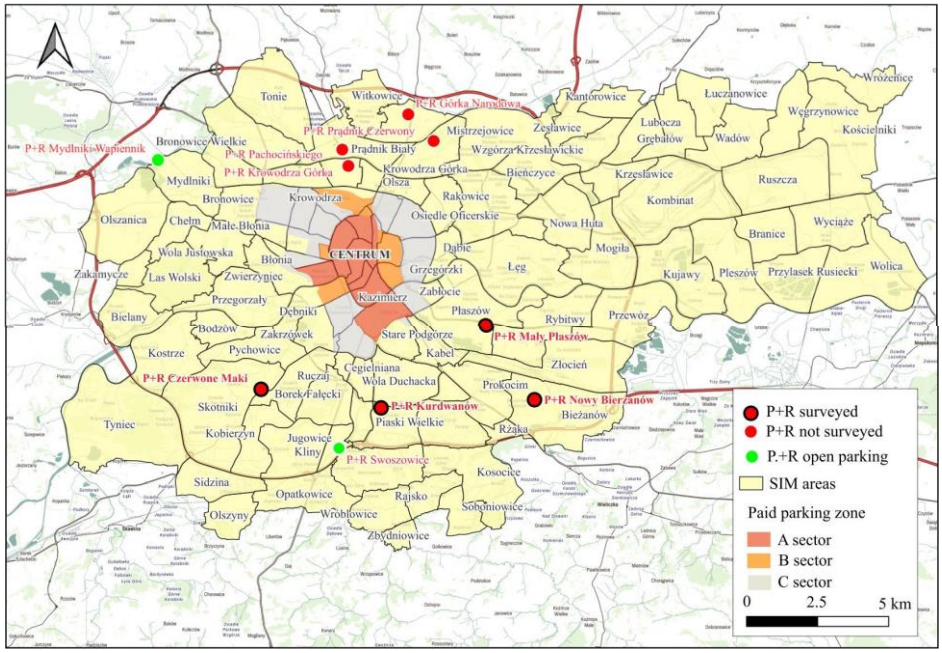


Figure 1. Distribution of P&R Car Parks in Krakow in 2025 in the Context of the Krakow Regional Transport Network.

Table 1. Distribution of P&R Car Parks in Krakow in 2025.

Location	P&R name	Number of parking spaces/ including spaces for people with disabilities
1.	Czerwone Maki	200/4
2.	Kurdwanów	167/7
3.	Bieżanów	110/5
4.	Mały Płaszów	165/7

5.	Mydlniki Wapiennik	85/6
6.	Swoszowice	154/6
7.	Krowodrza Górka	109/4
8.	Górka Narodowa Zachód	465/18
9.	Pachońskiego	95/3

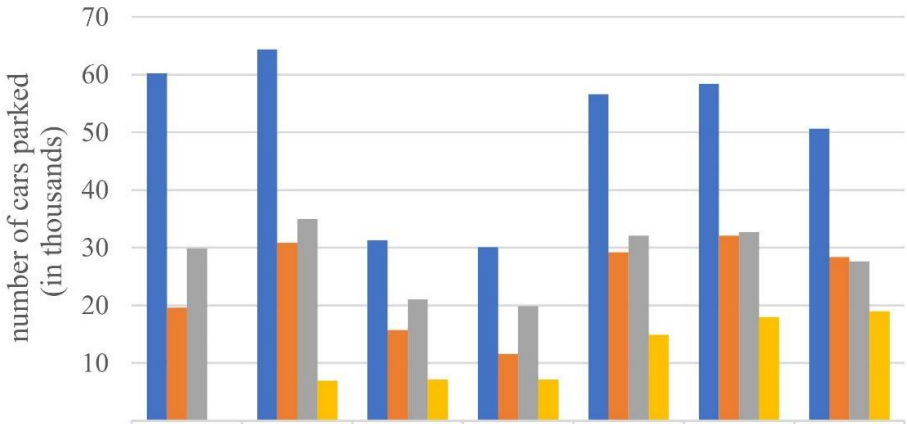
For other users, the price is PLN 10 (approx. 2.35 euros) per parking day (this is about 0.1% of average net earnings in Krakow). The car parks are open every day and are monitored from 4:30 a.m. to 2:30 a.m. the following day. An additional fee of PLN 250 (approxi-mately EUR 60) is charged for leaving a vehicle outside the designated parking hours. Battery charging fee for electric vehicles and hybrid vehicles for 1 kWh – PLN 2.3.

The remaining two car parks — Mydlniki Wapiennik and Swoszowice — operate in an open system. An open system means that ticket control at a given car park is carried out manually by the car park personnel, and there are no automatic barriers or gate systems in place. After parking, drivers must report to the car park personnel and present a valid public transport ticket in order to be exempted from parking fees.

It is worth noting that approx. 200,000 cars enter Krakow daily, and even if all P&R car parks were fully occupied, they would accommodate less than one percent of the incoming vehicles — assuming that all incoming cars used the parking spaces at the same time. The city's strategy has set a goal of creating over 4,000 parking spaces for passenger cars at P&R car parks by 2030, which would reduce the flows of intense vehicle traffic by only about two percentage points.

Variation in the number of cars using P&R facilities in Krakow between 2018 and 2024

The oldest Park and Ride (P&R) facility in Krakow is the Czerwone Maki car park, which has been in operation since July 2017. This car park has the highest occupancy rate due to its excellent location in relation to public transport, as well as its position within a district that hosts numerous corporate offices, the Jagiellonian University campus, and its library. Between 2017 and 2019, the number of vehicles using the car park increased from 57,900 to 64,300, reaching 111.1% of the initial volume (Fig. 2).



	2018	2019	2020	2021	2022	2023	2024
Czerwone Maki	60243	64348	31278	30083	56575	58414	50638
Kurdwanów	19575	30802	15707	11605	29220	32061	28349
Nowy Bieżanów	29868	34935	21068	19855	32080	32678	27639
Mały Płaszów	no data	6957	7150	7106	14895	17964	18998

Figure 2. Fluctuations in P&R occupancy 2018-2024.

Between 2019 and 2020, the number of vehicles decreased from 64,300 to 31,300, amounting to just 48.7% of the previous volume. This decline was due to the COVID-19 pandemic, during which most companies and institutions

switched to remote work, and education at all levels was conducted online for a period of time. Aside from the pandemic period, nearly every month of the timeframe under study shows either an increase in the use of the Czerwone Maki P&R facility or maintaining the number of vehicles, averaging over 5,000 per month. Between 2020 and 2024, the number of vehicles increased from 31,300 to 50,600, reaching 161.7% compared to the initial year.

In the use of the car park, there are clear regularities in terms of occupancy over the period of a year. The lowest occupancy rate is recorded during the summer holiday period, mainly in July and August. The increase in occupancy takes place since September and reaches its peak in October, coinciding with the start of the academic year, when students and university staff return to Krakow's higher education institutions.

The P&R Kurdwanów car park is located within the residential development area. Between 2018 and 2019, the number of vehicles at the car park increased from 19,600 to 30,800, reaching as much as 157.4% of the initial figure. In the following year, however, the number of parked cars decreased to 15,700, i.e. by approx. 50.0%. In the years 2020-2024, the number of parked cars increased again from 15,700 to 28,300, which amounts to 180.3% of the initial figure. Apart from the period of the pandemic and the long period of difficult access due to the construction of the so-called Łagiewnicka Route, a clear and significant increase in demand for parking at the Kurdwanów P&R facility can generally be observed. Similarly to the Czerwone Maki P&R, the same clear monthly rhythm in parking space occupancy is evident.
The Bieżanów P&R car park, located in a residential area on the outskirts of the eastern part of the city, saw the number of vehicles increase from 29,900 in 2018 to 34,900 in 2019, i.e. by 117.0%. It then decreased to 21,100 in 2020, which i.e. by 60.5%. Between 2020 and 2024, the number of vehicles increased from 21,100 to 27,600, i.e. by 130.8%. As with the previous case, despite strong interest in this car park, the pandemic period clearly impacted its usage.

P&R Mały Płaszów has been operating since April 2019 and the number of vehicles stopping in the car park generally increased from 7,000 to 19,000 thousand, i.e. by 368.3%. In this case, during the pandemic—especially in April and May 2020—there was a significant decrease in the number of parked vehicles, but on an annual basis this did not result in a significant decrease in the number of vehicles using this car park.

Similar monthly patterns in customer traffic and a growing demand for parking are observed at this car park. However, when comparing the monthly occupancy with other car parks, it turns out that interest in this car park is the lowest. This is due to its less favourable location (limited and poorly marked access to the car park, its location in the proximity of the city centre, and more limited opportunities for benefitting from the public transport).

Changes in the number of cars at P&R facilities in Krakow by months over the period of 2022-2024

In the subsequent stages of the study, the focus was placed on the period from 2022 to 2024, when the COVID-19 pandemic effectively came to an end (Fig. 3). The pandemic had a significant impact on the commuting behaviours of people traveling to work or school in Krakow (Bauer et al. 2021).

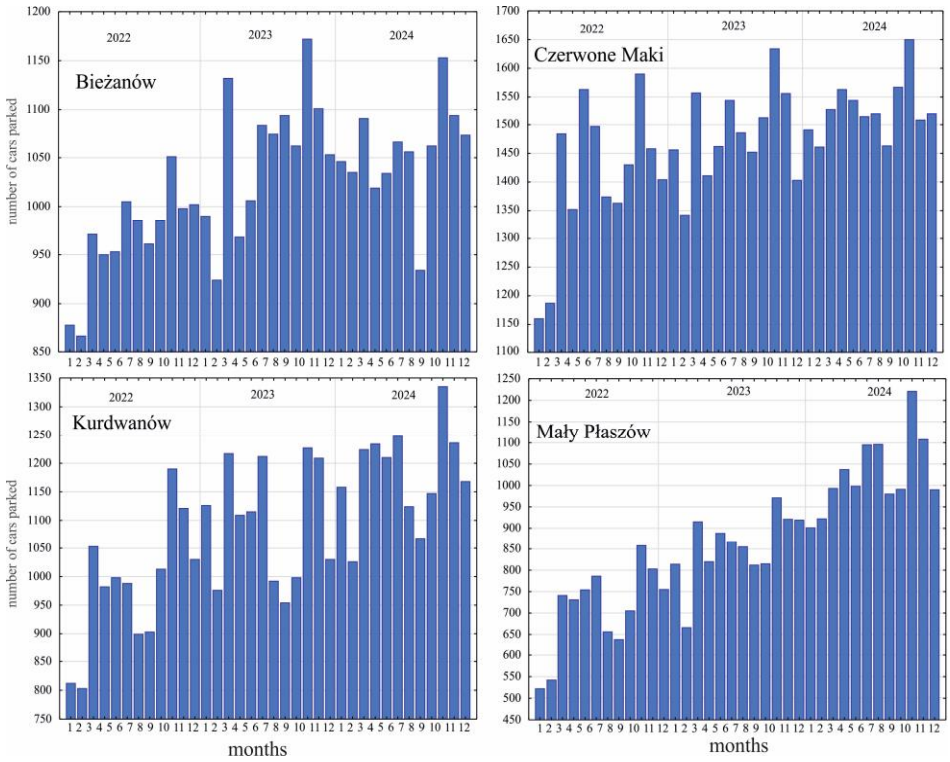


Figure 3. Changes in the number of vehicles using P&R facilities in Krakow by month between 2022 and 2024

The first question addressed in the analysis was whether the intensity of parking space usage in the four car parks analysed followed the same distribution over time and, therefore, whether they could be analysed jointly. In order to answer this question, distributional similarity over the study period was assessed using the Similarity procedure of the SAS statistical software (Rodriguez 2011). This procedure takes into account two ordered numerical sequences (input and target). The measure of similarity between the time series data analysed is a metric that measures the distance between the input and target sequences, taking into account the order of the data items. The Similarity proce-dure calculates similarity measures that "shift" the target sequence relative to the input sequence. These "shifts" can be based on the observation index (a measure of similarity between shifting sequences) or on the seasonal index (a measure of similarity between seasonally shifting sequences).
In order to compare the raw input data and raw target data to a timestamp, the raw data must be collected in a time-series format. Once the input and target time se-ries have been created, the two collected time series can be compared as two ordered nume-rical sequences. The higher the value returned by the procedure (greater distance), the more the data distributions differ from each other, which is represented by the colour red on the graph (Fig. 4).

The greatest differences during the years analysed were recorded between P&R Mały Płaszów and Czerwone Maki, while the smallest ones were recorded between Bieżanów and Kurdwanów. Based to the average minimum distance from other car parks, Czerwone Maki and Mały Płaszów differed the most. The greatest differences occurred at the beginning of the study period, in the first quarter of 2022 – still during the pandemic. The differences were so significant that, in subsequent analyses, changes in the number of occupied parking spaces on an annual basis were considered sepa-rately for each car park.

The monthly distribution of vehicle entry intensity varies, with a marked decrease during the summer holiday period (July and August) and an increase in October–November and in June. An analysis of the average vehicle entry distribution for individual car parks shows that the distribution for 2022 differs the most from the other years — a result of the COVID-19 pandemic. Only in the case of Bieżanów was the average number of vehicle entries in 2023 higher than in 2024.

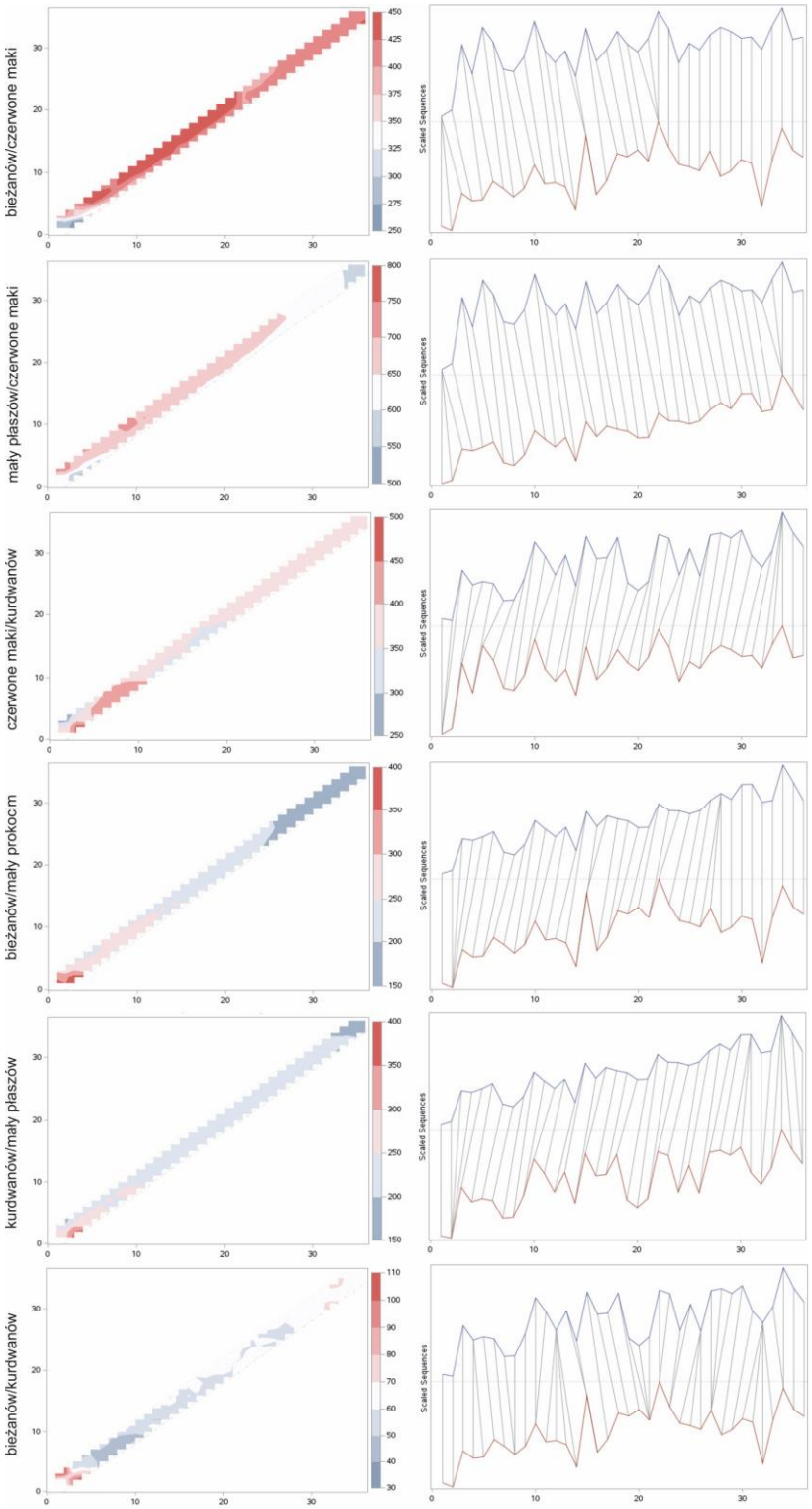


Figure 4. Similarity matrix of the distribution of car park occupancy values on a monthly basis, generated using the SAS Similarity procedure in the years 2022-2024.

In the further analysis, in order to compare the occupancy of individual analysed car parks, the monthly share was recalculated in relation to the annual number of vehicle entries to each car park. Then, the average value for the analysed years was calculated for each month (Fig. 5, 6, 7).

Table 2. Matrix of minimum distance values between the data items for the years 2022-2024.

P+R	Czerwone Maki	Bieżanów	Mały Płaszów	Kurdwanów	mean value
Czerwone Maki	-	16 056	21 795	13 519	17 123.33
Bieżanów	16 056	-	5 931	3 071	8 352.667
Mały Płaszów	21 795	5 931	-	7 460	11 728.67
Kurdwanów	13 519	3 071	7 460	-	8 016.667

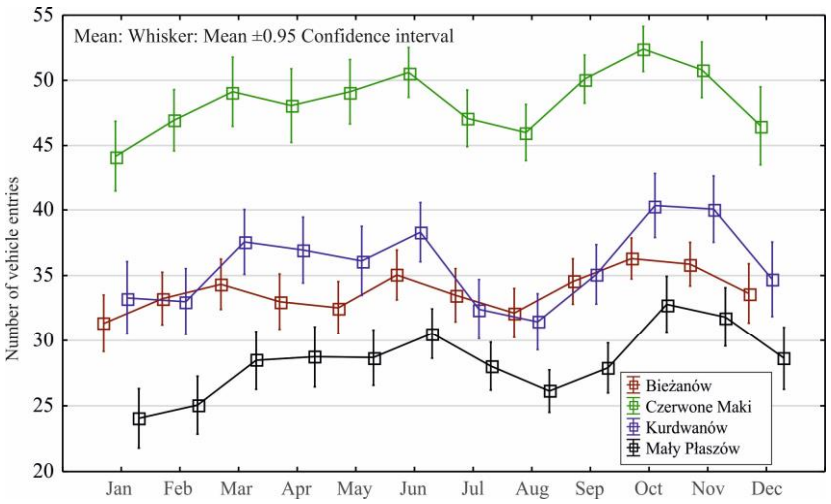


Figure 5. Average share of vehicle entries to P&R facilities in Krakow by month, 2022-2024.

An analysis of the monthly distribution of vehicle share shows that it is relatively consistent in the analysed years. The lowest share was recorded in February (school winter break period and the fewest days in the month) and during summer holidays (July–August), a period associated with annual leave and increased use of alternative means of transport, including motorcycles and bicycles (Dorocki 2022b). An increase in the number of vehicles using car parks in Krakow occurs in October (student arrivals). The apparent increase in the share in March and June is caused by a decrease in the number of vehicles during the winter school break (January–February) and the Catholic Easter holidays (usually in April).

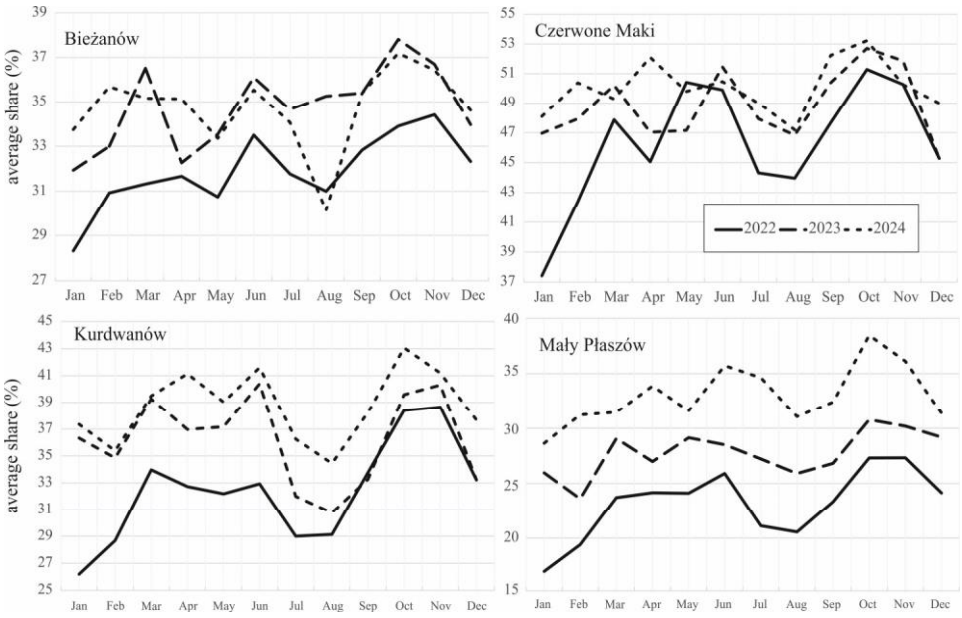


Figure 6. Average share of vehicle entries by month in individual years, 2022-2024.

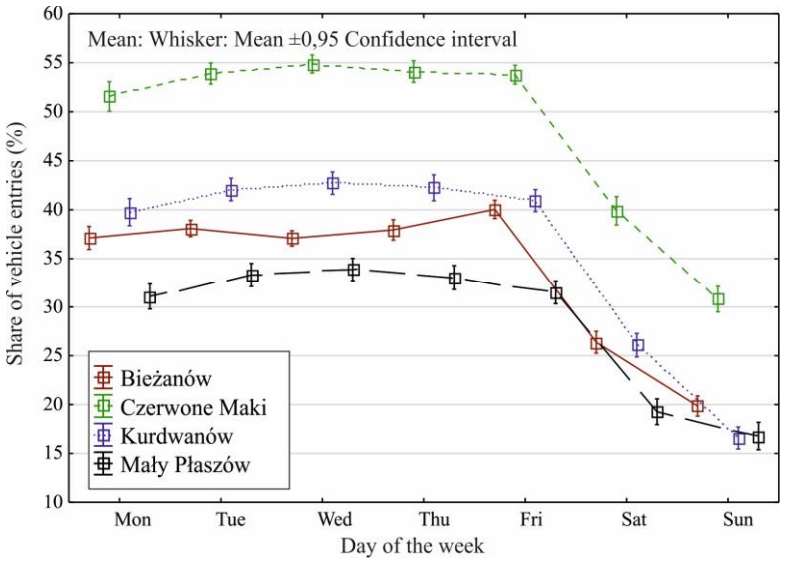


Figure 7. Average share of vehicle entries to P&R facilities in Krakow on a monthly basis, in the years 2022-2024.

Variation in the number of cars using P&R facilities on a weekly basis, 2022-2024

In the next stage of the study, changes in the intensity of cars using the car parks were identified on a weekly basis. The mode of the number of vehicles for all P&R facilities, except Bieżanów (where the highest number of vehicles is recorded on Fridays), falls on Wednesdays (Fig. 8, 9).

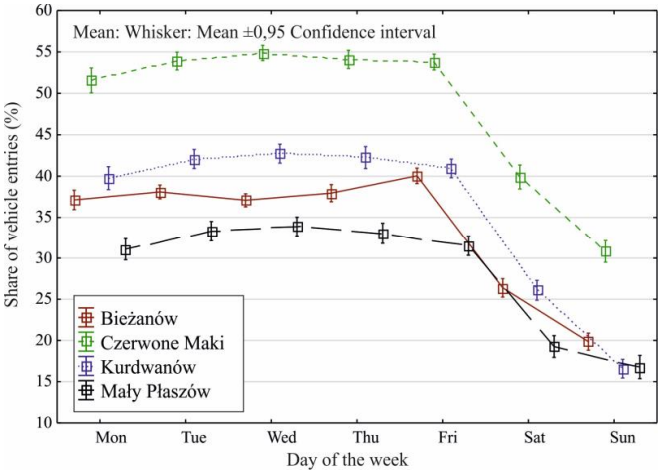


Figure 8. Average share of vehicle entries by day of the week, in the years 2022-2024.

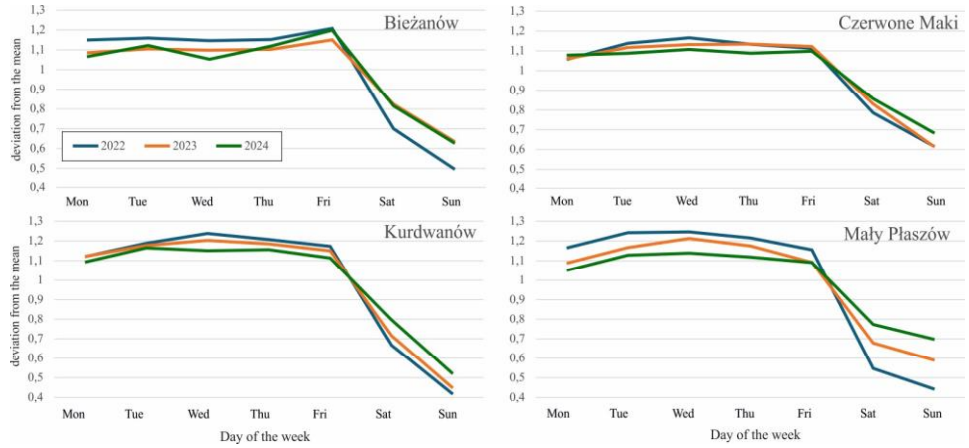


Figure 9. Changes in the average number of vehicles at individual P&R facilities in Krakow by day of the week, 2022-2024 (relative to the weekly average).

The lowest values appear on Saturdays and Sundays, which indicates that the car parks are used primarily by commuters. However, as can be seen from the analysis of individual years, the share of vehicles at weekends keeps increasing (especially at Mały Płaszów), while weekday numbers are decreasing — except on Fridays and Mondays at Czerwone Maki. This suggests that car parks are also used for recreational trips. The increased attractiveness of using the Mały Pałaszów P&R was due to the launch of a new weekend bus line 497, which connects the "Mały Płaszów" P+R car park with "Bagry Tężnia". It runs every 20 minutes during peak hours (around 10:00-18:00) and every 40 minutes outside these hours, be-tween 9:00-20:00. A ticket for this line costs PLN 5 (approximately EUR 1) and is valid for the whole family.

In the analysis of daily changes, a 7-day moving average was applied to account for weekly variation in vehicle intensity. The average car park occupancy was there-fore calculated (with full occupancy corresponding to 100%), followed by the calculation of a 7-element (days of the week) moving average.

An analysis of the average occupancy share shows a continuing increase in the years 2022–2024. The largest increase was recorded at the Mały Płaszów car park, while the smallest increase was recorded at the Bieżanów car park. At all car parks, the lowest values were recorded at the turn of the year (the Catholic Christmas holiday and New Year's Eve/New Year). In the distribution analysed, a decrease in the variation of the number of parked vehicles in the years 2022–2024 is noticeable, mainly during the summer holiday period (Fig. 10).

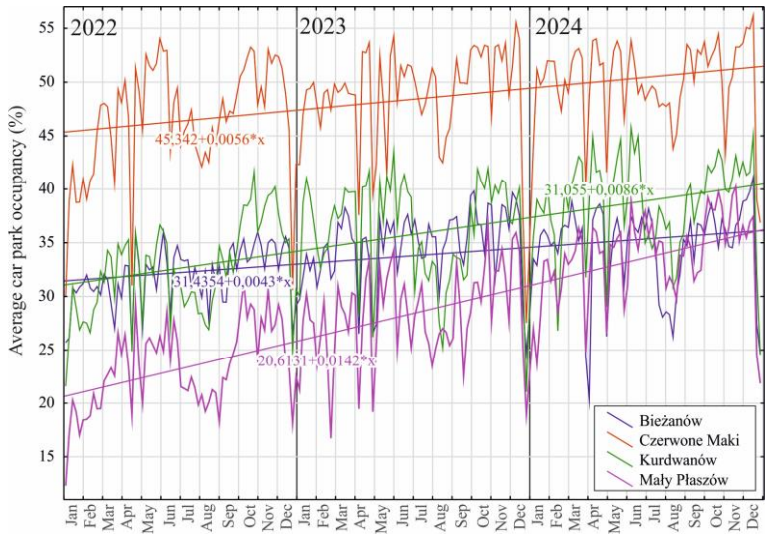


Figure 10. Average car park occupancy in the years 2022–2024 (7-element moving average, %).

As a result, the coefficient of the variation in the vehicle count by day decreased in the individual years analysed (Fig. 11). The Bieżanów car park, where the value remains nearly unchanged in 2023 and 2024, is an exception.

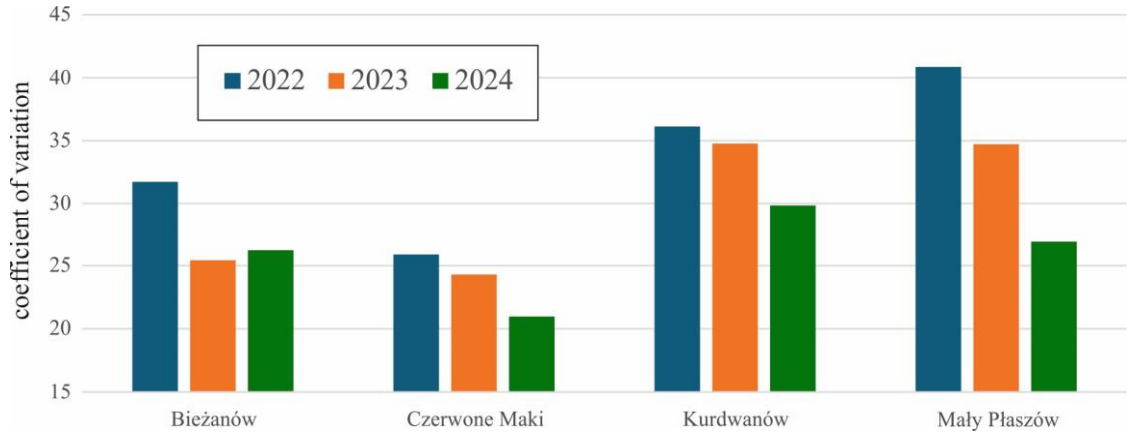


Figure 11. Change in the coefficient of variation in the vehicle count at P&R car parks in Krakow, in the years 2022-2024.

An analysis of the distribution for individual months shows that the daily decrease in the variation in vehicle numbers (changes by day) is most visible during the summer period (especially Mały Płaszów) and during the pandemic period in 2022 (January–March 2022) at the Bieżanów and Czerwone Maki car parks (Fig. 12). On a weekly basis, the decrease in the value of the coefficient of variation for car park occupancy is not as clearly visible as on a monthly basis, except for weekends (Fig. 13).

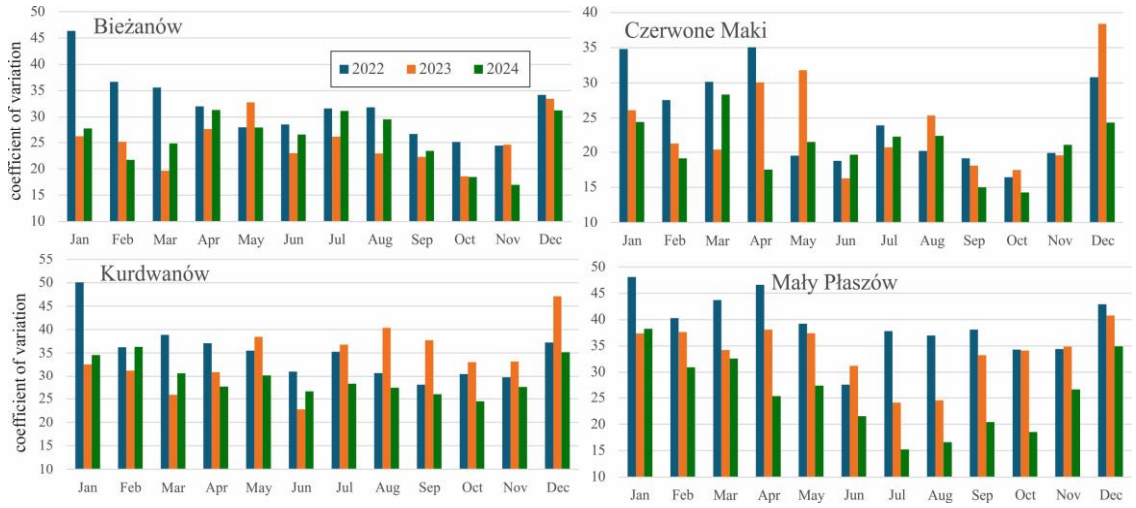


Figure 12. Change in the coefficient of variation of the daily vehicle count fluctua-tions at P&R car parks in Krakow by month in the years 2022–2024.

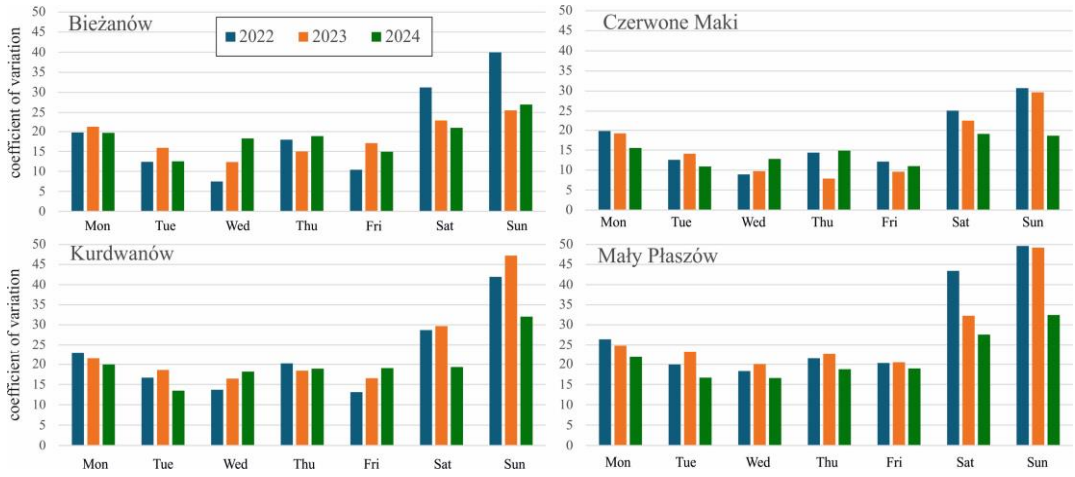


Figure 13. Change in the coefficient of variation for occupancy at P&R car parks in Krakow by day of the week in the years 2022–2024.

Only the combination of weekdays and months reveals the impact of Catholic public holidays (statutory non-working days in Poland) on the variation in the number of vehicles (Easter Monday in April, Corpus Christi on a Thursday in June, Christmas in December, and New Year's Day in January) (Table 3).

Table 3. Coefficient of variation the number of vehicles at P&R car parks in Krakow by months in the years 2022– 2024

months				**days of the week**			
January	9.55	4.96	4.61	9.88	8.46	9.08	6.12
February	4.99	4.59	4.11	6.71	5.39	6.56	4.96
March	3.50	3.76	3.68	3.86	5.94	8.74	8.02
April	14.60	4.53	4.00	3.47	6.71	8.21	9.69
May	8.59	8.52	9.85	8.14	7.84	9.84	6.59

June	3.54	4.04	4.82	10.60	5.77	5.91	7.04
July	3.81	4.16	4.11	5.37	4.80	6.04	6.25
August	8.01	6.46	4.11	6.91	4.93	5.88	5.64
September	4.63	4.32	4.35	4.38	4.08	6.19	5.85
October	4.77	3.85	3.88	4.53	4.14	4.73	5.94
November	5.82	6.12	4.93	4.19	6.70	5.66	5.55
December	13.80	12.09	9.80	9.64	6.14	9.08	7.93

It seems that the changes in the occupancy of car parks will be best shown by the hourly distribution. For this purpose, the day was divided into 15-minute periods and the average occupancy of car parks was calculated, in relation to the number of all available spaces (100%). Among the analysed car parks, Bieżanów and Czerwone Maki recorded the highest average occupancy, while Mały Płaszów had the lowest (Fig. 14). The monthly distribution is similar for all car parks and is characterized by the highest occupancy in October and March, and the lowest in August and December/January.

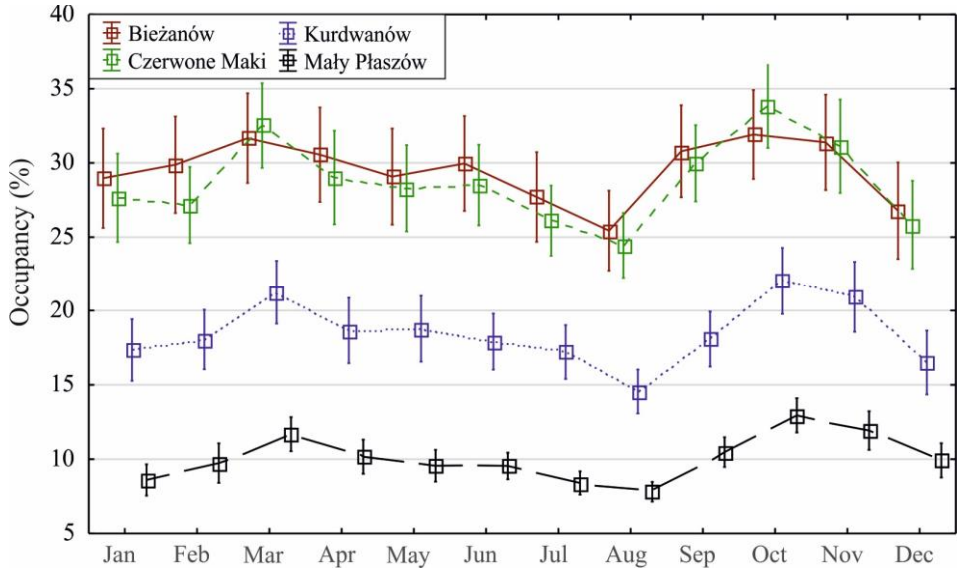


Figure 14. Average share in % of car park occupancy by months for the years 2022-2024.

When broken down by individual years, based on average occupancy calculated for fifteen-minute intervals, an upward trend can be observed, with the most significant increase occurring in 2023 (Fig. 15). In order to take into account the weekly periodicity of car park occupancy, a 7-day moving average was calculated from time data (15 minutes). The data obtained indi-cates mainly increasing drops in occupancy during the holiday period except for Mały Płaszów (Fig. 16).

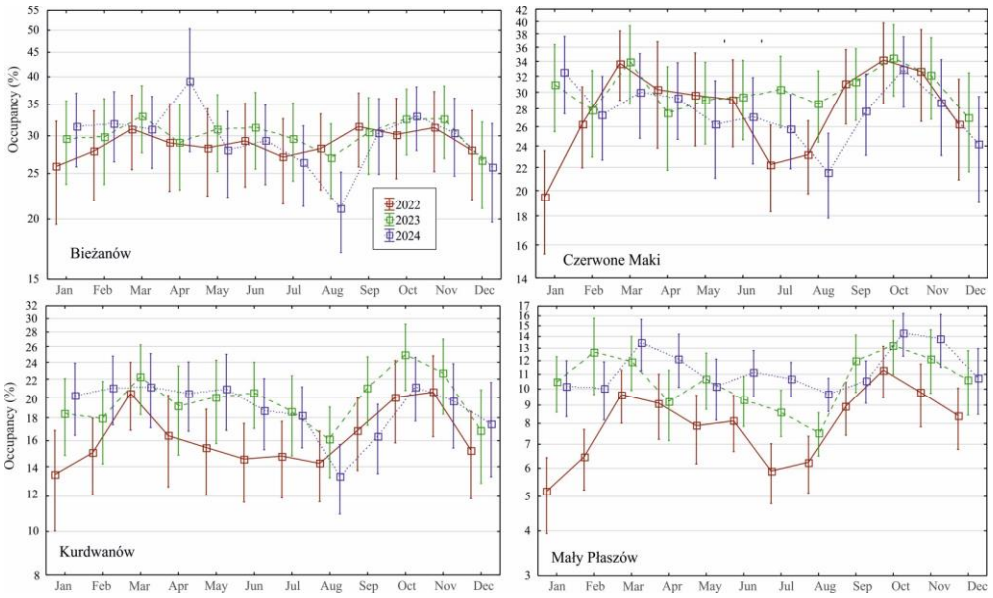


Figure 15. Average occupancy of parking spaces based on class ranges in the years 2022-2024

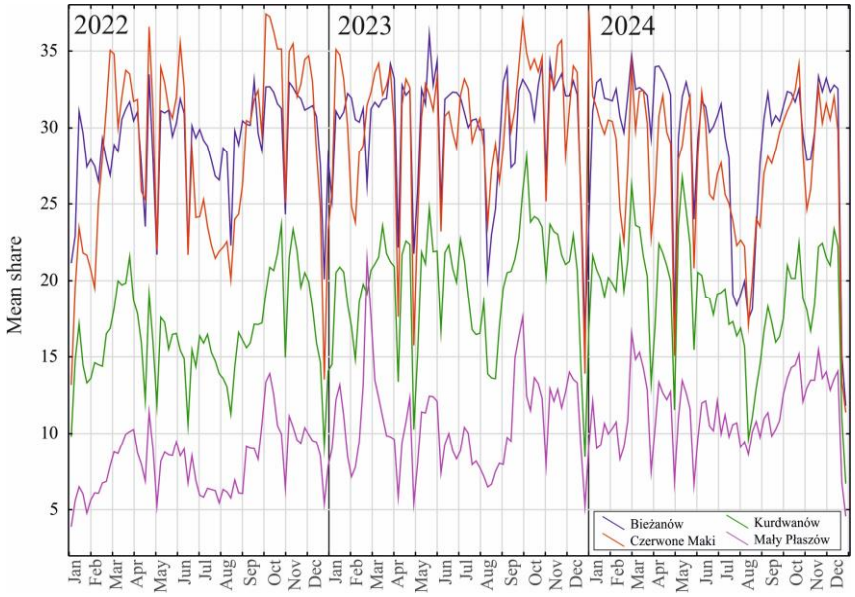


Figure 16. 7-element moving average of car park occupancy in the years 2022–2024.

In the daily distribution of average occupancy based on data from time intervals, the highest occupancy occurs on Tuesday and Wednesday, and on Friday during the week (Fig. 17). On Fridays, the share of average occupancy decreases significantly in the analysed period of 20222024. This appears to result from the fact that many companies introduced remote work on the last working day of the week. On the other hand, the average occupancy increases on Wednesdays and Tuesdays.

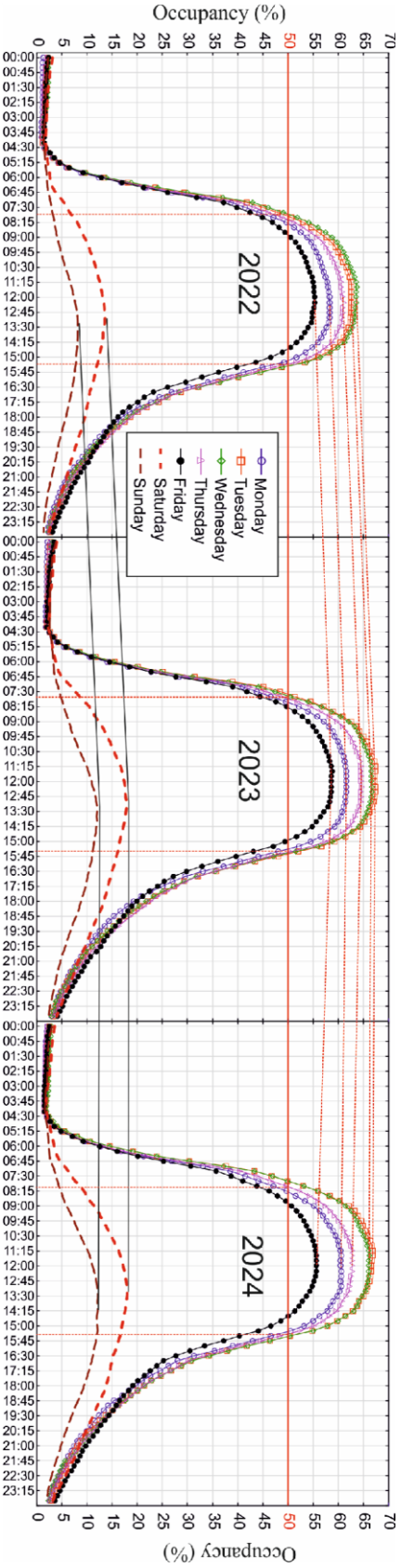


Figure 17. Share of average occupancy rates in the analysed car parks by month.

The average occupancy of car parks on Sundays is also increasing in a similar manner, which may be due to the growing tourist traffic. On an hourly basis, the highest average of over 50% of occu-pancy was recorded from 8.00 to 15.00 – which may confirm that the car parks are mainly used by people commuting to work in Krakow.

When analysing the average vehicle entry time over the analysed years, a delay of approximately 10 minutes per year was observed (Table 4), which may be caused by an increasing number of people working in corporations where work starts at 9 or 10, and there is often an hour break for lunch, which some people already use in the morning. In addition, employers note that people from the "generation Z" approach the start time at work very flexibly and very arrive late for it (Bińczyki et al. 2023). In all car parks, the latest average vehicle entry time was on Friday. A large difference in the time of vehicle entry occurred between Bieżanów and Mały Płoszów (here it was later), which may result from the location of the latter car park closer to the city centre – i.e. shorter travel time by public transport or on foot to the centre.

Table 4. Average time of entry by weekdays at individual P&R car parks in Krakow in the years 2022-2024.

days	Bieżanów			Czerwone Maki			Kurdwanów			Mały Płaszów			total
Mon	8:03	8:07	8:19	9:07	9:18	9:26	8:52	8:57	9:19	9:24	9:31	10:07	9:02
	8:02	8:07	8:17	9:13	9:13	9:18	8:50	8:53	9:11	9:13	9:37	9:57	8:59
	7:53	8:15	8:15	9:14	9:18	9:21	8:48	9:01	9:13	9:15	9:38	10:02	9:01
	8:06	8:24	8:22	9:22	9:27	9:36	8:54	9:03	9:15	9:26	9:41	10:17	9:10
	8:10	8:21	8:43	9:21	9:30	9:40	8:58	9:08	9:29	9:37	9:45	10:18	9:13
	11:02	11:25	11:46	10:53	11:13	11:40	11:02	11:06	11:17	12:01	12:28	12:48	11:29
	11:56	11:59	12:14	11:53	11:44	12:11	13:02	12:42	12:15	13:19	13:05	13:15	12:20
total	8:19	8:36	8:46	9:27	9:34	9:44	9:05	9:14	9:32	9:41	10:03	10:35	9:22

In the case of vehicle departures from the car parks, the situation is not as clear as in the case of vehicle entries. The latest vehicle departures were recorded at weekends (visits to Krakow for entertainment purposes – cinema, theatre, concerts – which are usually made in the evening). In contrast, the earliest vehicle departures were recorded on Fridays, which may be linked to the start of the weekend and shortened working hours in some workplaces (Gruza, Jurkiewicz, 2024). It should be noted that the time of vehicle departure did not change much and there is no constant trend – unlike in the case of changing the time of entry to the car park (Table 5). This is due to the fact that a large number of people living outside Krakow tend to run errands or do the shopping after work, which can significantly affect their departure time.

Table 5. Average time of vehicle departure by weekdays at individual P&R car parks in Krakow in the years 20222024

days	Bieżanów			Czerwone Maki			Kurdwanów			Mały Płaszów			total
	2022	2023	2024	2022	2023	2024	2022	2023	2024	2022	2023	2024	
Mon	16:24	16:19	16:28	16:13	16:23	16:11	16:23	16:22	16:11	16:29	16:07	16:23	16:19
	16:27	16:30	16:30	16:08	16:20	16:06	16:27	16:29	16:19	16:36	16:06	16:28	16:20
	16:28	16:30	16:31	16:14	16:23	16:17	16:25	16:27	16:24	16:30	16:21	16:24	16:23
	16:32	16:32	16:28	16:16	16:25	16:22	16:29	16:03	16:11	16:30	16:06	16:41	16:22
	16:19	16:12	16:13	15:57	16:06	15:59	16:04	16:07	15:39	16:14	15:59	16:03	16:04

	16:50	16:34	16:41	16:15	16:21	16:24	15:46	15:48	16:03	17:02	16:17	16:51	16:23
	17:05	16:57	16:56	16:41	16:37	16:53	17:08	16:59	16:22	16:39	16:47	17:01	16:49
total	16:29	16:27	16:28	16:11	16:20	16:14	16:22	16:17	16:10	16:30	16:11	16:29	16:19

Analysing the average hours of vehicle entry and departure, it turns out that on average cars are left in car parks for about 7 hours a week (including the shortest duration on Friday), 5 hours on Saturday and 4.5 hours on Sunday. At P&R Bieżanów they are left for about 8 hours, and at Mały Płaszów for about 6 hours. At the other two car parks, the average parking time is about 7 hours (Table 6). It is worth noting that, in the case of all car parks, the average parking duration decreased, which may indicate a shift from office work towards shorter working hours and an increase in remote work.

In the case of the monthly distribution, there are no such clear changes in the aver-age hourly occupancy of the car parks in the analysed period of 2022-2024. It is only possible to track visible, decreasing occupancy of car parks during the summer holidays (July-August) and December (Christmas and New Year). Very low values were recorded in January 2022, which was additionally affected by the Covid 19 pandemic.

Table 6. Average duration from entry to departure at individual P&R car parks in Krakow by day in the years 2022–2024.

days of the week	Bieżanów			Czerwone Maki			Kurdwanów			Mały Płaszów			total
	2022	2023	2024	2022	2023	2024	2022	2023	2024	2022	2023	2024	
Mon	8:20	8:12	8:09	7:05	7:05	6:44	7:31	7:24	6:51	7:04	6:36	6:16	7:17
	8:25	8:23	8:13	6:55	7:06	6:48	7:37	7:35	7:08	7:22	6:29	6:30	7:20
	8:34	8:15	8:15	7:00	7:05	6:55	7:37	7:25	7:11	7:15	6:43	6:22	7:22
	8:26	8:08	8:05	6:53	6:58	6:46	7:34	6:59	6:56	7:03	6:24	6:24	7:12
	8:09	7:51	7:29	6:36	6:36	6:18	7:05	6:58	6:09	6:37	6:13	5:44	6:50
	5:47	5:09	4:55	5:22	5:07	4:43	4:44	4:41	4:46	5:00	3:48	4:02	4:53
	5:08	4:57	4:42	4:48	4:53	4:42	4:05	4:16	4:06	3:19	3:42	3:45	4:28
total	8:09	7:50	7:42	6:44	6:46	6:29	7:16	7:03	6:38	6:49	6:07	5:54	6:57

The average parking duration decreased most significantly during the summer period (July–August), by approximately 45 minutes. This was mainly the result of the later time of entry to the car park (Table 7).

Table 7. Average time elapsed from vehicle entry to departure at individual P&R car parks in Krakow in 2022– 2024 by month.

months	time of entry			time of departure			parking time		
	2022	2023	2024	2022	2023	2024	2022	2023	2024
Jan.	9:02	9:08	9:18	16:26	16:26	16:06	7:24	7:18	6:48
Feb.	9:00	9:04	9:21	16:24	16:10	16:07	7:23	7:06	6:46
Mar.	8:53	9:07	9:26	16:07	16:22	16:03	7:13	7:15	6:36
Apr.	9:04	9:17	9:32	15:54	16:28	16:25	6:50	7:11	6:52
May	9:10	9:18	9:39	16:22	16:19	16:17	7:12	7:01	6:38
Jun	9:16	9:24	9:49	16:19	16:19	16:17	7:03	6:55	6:28

Jul	9:08	9:19	9:41	16:31	16:20	16:22	7:22	7:01	6:41
Aug	9:13	9:29	9:54	16:39	16:28	16:31	7:26	6:59	6:37
Sep	8:59	9:25	9:36	16:27	16:25	16:22	7:27	6:59	6:45
Oct	9:16	9:21	9:33	16:26	16:15	16:22	7:09	6:53	6:49
Nov	9:08	9:29	9:42	16:13	16:13	16:28	7:05	6:44	6:45
Dec	9:15	9:41	9:52	16:21	16:16	16:23	7:05	6:35	6:31
year	9:07	9:20	9:36	16:20	16:20	16:18	7:12	7:00	6:42

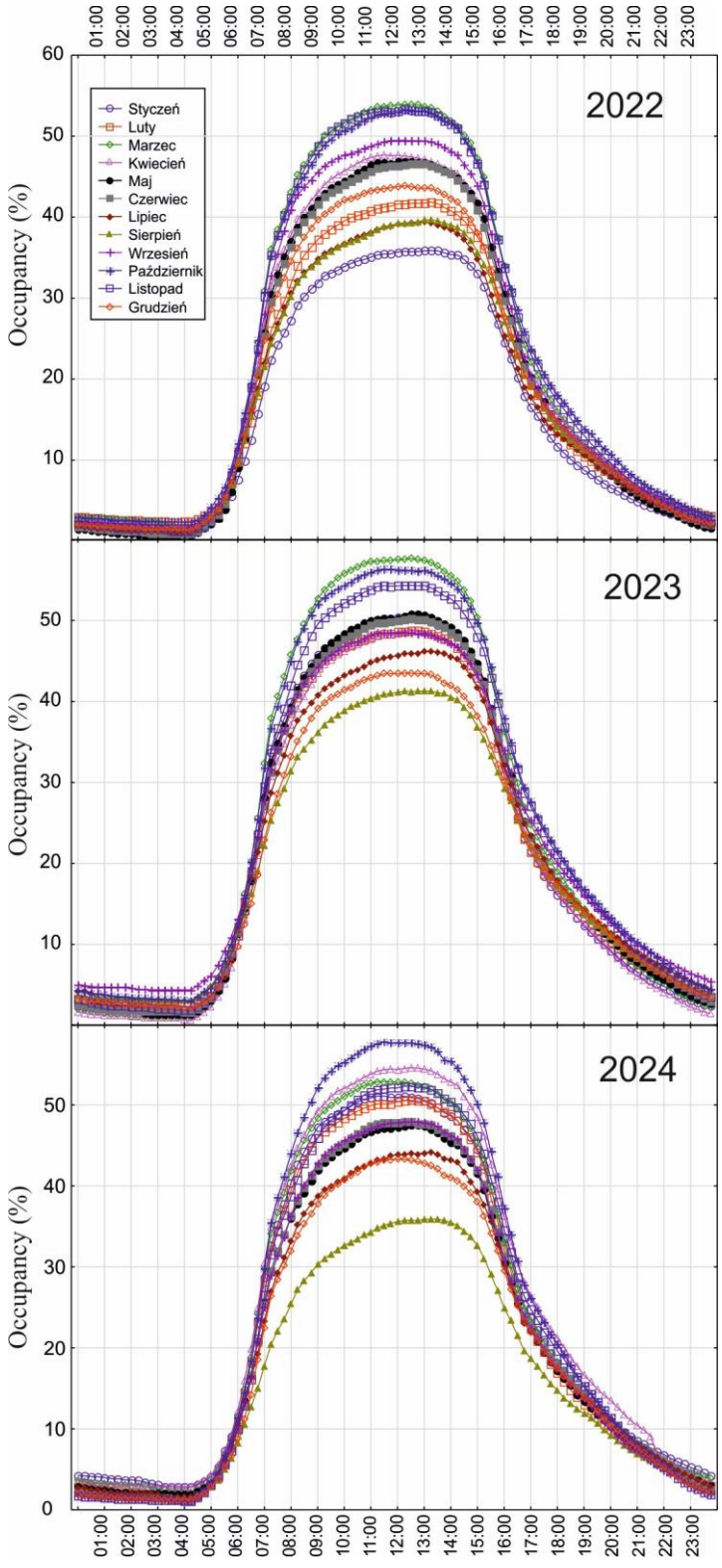


Figure 18. Share of average occupancy rates at the analysed car parks by month.

This may suggest that during the vacation period, employees tend to take a more relaxed approach to their working hours. This may be particularly evident in companies where there is no direct contact with the customer, e.g. in outsourcing and business services, which is a dominant sector in Krakow (Ziółkowski, Gawron 2022).

At the end of the analysis investigating the use of P+R car parks in Krakow, the number of vehicles using individual car parks was correlated with their parking time. In this way, the daily number of vehicle-hours was

calculated. This index is influenced by the number of cars, as well as the length of time over which they are parked at the car park. Additionally, the popularity of a given car park was calculated as a 7-element moving average, taking into account weekly periodicity (Fig. 19).

When considering the values of the index for the years 2022–2024, it is observed that it begins with low values in January and February 2022. This is most likely an outcome of the Covid-19 pandemic (Figure 19 showcases the time period of: a.—the end of restrictions related to the Covid-19 pandemic in Poland; b.—the end of the Covid-19 pandemic in Poland).
There is little variation in the values of the index in the analysed years, as it remains at a similar level. A slight decrease was recorded at the Czerwone Maki, Kurdwanów, and Bieżanów car parks, while an increase was recorded at Mały Płaszów.

In all of the analysed car parks, there are fluctuations in the value of the index, with a drop of values during the winter holidays, Catholic Easter holidays (spring), May holidays (1st and 3rd of May, which are public holidays in Poland), summer holidays (July and August), and the period from Christmas to New Year. This demonstrates that car parks are mainly used by people commuting to work in Krakow. The lowest fluctua-tions in the value of the indicator were recorded at the Mały Płaszów car park, while the largest—at the Czerwone Maki car park. This is mainly due to their location relative to the city centre and the difference in the purposes of underlying arrivals in the city (Mały Płaszów car park is also used by tourists).

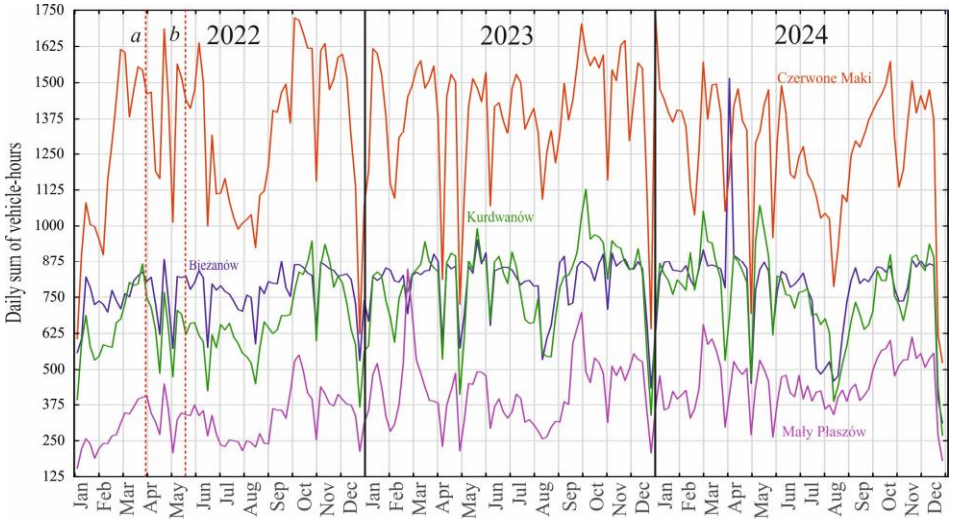


Figure 19. 7-element moving average of the daily number of vehicle-hours.

Conclusion

In the light of the analyses presented, it was demonstrated that there was an in-crease in the demand for P&R car parks in Krakow during the period under study. The new large investments in the northern part of the city have only partially met the major investment needs in the area, which has been completely deprived of this type of parking infrastructure for cars until 2025. The increase in the demand for the P&R system was halted due to the Covid 19 pandemic, but currently a renewed increase in car park occupancy can be observed.

Among the car parks under study, Bieżanów and Czerwone Maki had the highest average occupancy rates in the analysed years, with Mały Płaszów having the lowest, although there is a constant increase in occupancy in the latter. In all of the P&R car parks, a degree of rhythmicity is observed, which results from the holiday period and the changes in traffic flow caused by the function of Krakow as an academic centre. The month-by-month distribution displays the highest occupancy rates in October (when students and university employees return), and the lowest in August (summer holidays) as well as in late December/early January (winter holidays).

On a weekly basis, the lowest numbers of parked vehicles are recorded on Saturdays and Sundays, which testifies to the car parks being used mainly by commuters, alt-hough measures are being taken to propagate the use of car parks for recreational trips at weekends. In the daily distribution, the highest occupancy rates at P&R facilities are observed on Tuesdays and Wednesdays, and the lowest on Fridays (remote work). When analys-ing the average time of vehicle entry and departure, it becomes apparent that, on aver-age, during the week, cars are left at a car

park for around 7 hours, on Saturdays for 5 hours, and on Sundays—for 4.5 hours. In recent years, we can observe a shift in the timeframe of car park occupancy, mainly due to later arrivals at work and in-creased popularity of remote work.

Due to the fact that P&R car parks occupy high-value urban areas, require investment and operating expenditure, raise public protests as well as cause doubts with regard to the likelihood of finding users for their system, an important research problem is the assessment of this system's effectiveness in the transport policy of Krakow. In the further stages, the research work will aim to explore the possibilities and obstacles of new P&R locations, assess user feedback on their performance, and determine the op-portunities to increase the attractiveness of P&R and change commuting-related habits.

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