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THE IMPACT OF INTRODUCING NEW STOPS INTO THE AGGLOMERATION RAILWAY NETWORK ON CHANGES IN TRANSPORT BEHAVIOUR IN THE CATCHMENT AREA – CASE STUDY OF KRAKÓW AND ŁÓDŹ, POLAND

Sabina PUŁAWSKA-OBIEDOWSKA[1], Aleksandra CIASTOŃ-CIULKIN[2], Mariusz SOBOŃ[3]

[1,2,3] Faculty of Civil Engineering, Department of Transportation Systems, Cracow University of Technology, Cracow, Poland

Abstract:

The aim of the analysis is to examine the impact of new railway stop openings within suburban railway network on changes in transport behaviors within their respective catchment areas. The study focuses on six railway stations: four located within the Kraków suburban railway network (malopolskie, Poland) and two on the Łódź suburban railway network (lodzkie, Poland). To achieve the stated objective, the spatial context and accessibility of the railway stations were examined, passenger exchange data at the stations were investigated, and surveys among passengers were conducted and analyzed. The selected railway stops were characterized in terms of their spatial location and characteristics, existing transport systems, and the level of integration with other transport modes. The study examined stations established during the development of suburban railway systems, launched at different times: concurrently with the entire railway connection launch and as densification of previously served networks. The limited number of objects included in the study does not allow for unequivocal conclusions on expected increase in transportation, but certainly, in the first two years following their launch, a monthly average increase of 4-6% can be anticipated. Research has confirmed that the most common rail passengers are former users of other means of public transport. The pattern of giving up cars in favor of the train was also confirmed. The outcomes confirm the justification for supplementing agglomeration railway systems with new stops, as this may contribute to a change in modal split. This change may not be noticeable in view of the usually considered large scale of the agglomeration, but on individual corridors in a micro scale it may have a very positive impact on the traffic situation and change the quality of travel. Results can be used to forecast changes in travel behaviors for planned railway stations and to determine their potential benefits.

Keywords: *suburban railway, urban railway, transport behaviour, railway stations, agglomeration, catchment area, accessibility*

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Contact:
1) sabina.pulawska@pk.edu.pl [https://orcid.org/0000-0001-7053-2959] – corresponding author; 2) aleksandra.ciaston-ciulkin@pk.edu.pl [https://orcid.org/0000-0003-0259-1265]; 3) mariusz.sobon@pk.edu.pl [https://orcid.org/0009-0006-5769-8800]

1. Introduction

Public transport is one of the key aspects of the development and functioning of metropolitan areas. Reducing congestion, limiting greenhouse gas emissions, and improving residents' quality of life are currently the main challenges for planners and local authorities. Rail is undoubtedly a much more competitive means of transport than bus or tram lines due to its high capacity, short travel time, lower unit operating costs, and independence from road congestion. At the same time, it is significantly cheaper than the metro, considering construction process. Consequently, many local governments in Poland recognize its competitive advantage over other means of transport and support its development through the expansion of the rail network, increasing the accessibility of passenger interchange points, improving transport services, as well as integrating it with other transport modes (Wolowiec, 2021). In recent years, one may observe a significant development of suburban rail systems in Poland, which have begun to operate to serve commuting flows to places of education and work for people living in metropolitan areas or more distant towns. Rail transport within large urban agglomerations is becoming increasingly important due to the presence of road congestion. The development of suburban rail systems can be crucial for serving residential areas in the peripheral parts of the city, where other transport services are often insufficient, and travel is hindered by congestion.

According to statistics maintained by the Polish Office of Rail Transport (pol. Urząd Transportu Kolejowego - UTK), the significance of suburban railways is increasing, considering the activities of railway companies that operate solely within metropolitan areas and nearby smaller cities. This is particularly true for large metropolitan areas in voivodeships such as Pomeranian, Mazovian, Lower Silesian, Łódź, and Lesser Poland, where there is a noticeable upward trend in the volume of transport services provided. The Pomeranian voivodeship had the highest rail usage rate, recorded at 26.95 trips per resident in the voivodeship in 2022. This is due to the activities of PKP SKM (Tri-city Rapid Transit Rail), which plays a significant role in the urban transport system in the metropolitan area. Additionally, it has an independent, dedicated infrastructure, which allows for the efficient use and operation of this form of rail. The development of regional and suburban transport is also significantly influenced by changes in transport services and the participation of local governments. Examples include Małopolskie Railways (KMŁ) and Łódź Agglomeration Railway (ŁKA), whose transport volumes have been steadily increasing over the past 10 years (UTK, 2021).

The extent to which suburban rail can play a significant role in the modal share will also depend on the population size and its distribution in relation to the rail infrastructure. A rail network located in proximity to residential, industrial, and service areas will increase the attractiveness of rail as a means of transport characterized by the certainty of travel in a planned, congestion-independent, and usually the shortest time (Kotula, 2020). The task suburban railways should fulfill is to meet the transport needs of people living in areas adjacent to the agglomeration and commuting to work or school in a larger urban center, as well as the internal transport needs within the agglomeration. This system mainly serves the commuters, who travel during peak traffic hours (morning to work/school and afternoon back home). The frequency of suburban trains is high, the distance between stops is short, there are many stops, and the network of connections is linked and integrated with the networks of other means of transport. Travel by suburban rail usually takes a short time (up to half an hour) (Centrum Unijnych Projektow Transportowych, 2022). Meeting these expectations can contribute to changing transport behaviors, with many studies indicating that the majority of suburban rail passengers are former users of other forms of public transport. Private cars are much less frequently abandoned in favor of rail services, although this can depend on specific rail connections (e.g., from 25% for SKA2 or SKA3 to over 40% for SKA1 in the Kraków agglomeration) (Kulpa, Kulas, & Popadiak, 2017).

The purpose of the analysis presented in the article is to examine the impact of the introduction of new railway stops on the suburban rail network on changes in transport behavior in the catchment area. The research is based on survey studies conducted among rail passengers and residents of the areas affected by six new railway stops (four of which are located on the Kraków suburban railway network (SKA) – Kraków Złocień, Kraków Grzegórzki, Kraków Bonarka, and Wieliczka Bogucice, and the remaining two on the Łódź suburban railway network

(ŁKA) - Pabianice Północne and Zgierz Rudunki). The survey studies focused on transport preferences and behaviors and were conducted using direct interviews. The examined stops were characterized in terms of their spatial location, spatial development features in the vicinity, the existing transport system, and the quality characteristics of rail connections provided from the stop. An analysis of the dynamics of passenger traffic changes at the newly opened stop was also conducted, considering the importance of accessibility (a large number of stops) as a feature significant from the passenger's point of view and defining the concept of suburban railways.

In the subsequent section of the article, a literature review on issues connected with new railway stop and stations together with travel behaviour of rail transport passengers in agglomerations was conducted. Following this, the research tools and methods for data analysis were described in detail. The third part of the article presented the most important findings from the conducted studies, and the article concluded with a section containing a discussion of the topic, conclusions, and a summary.

2. Literature review

The topic of the impact of launching new railway stops has been addressed by many authors dealing with transportation issues. Railway stations serving local traffic can perform various functions, which may affect the transportation habits of passengers in their area of influence. One of the primary classification criteria includes differentiation based on the spatial development of the area adjacent to the railway station. (Li, Zhou, & Dong, 2020) in their study for Beijing, identified six types of railway stations differing in the distribution of passenger flow in various directions, hours, and days of the week. The following types were distinguished:

- Transportation hub and tourism commercial,
- Residential,
- Office,
- Mixed living and office,
- Residential and office mixed but partial living,
- Residential and office mixed but partial office.

Another criterion was indicated in an analysis concerning the effects of new railway stations in metropolitan areas in Sweden (Adolphson & Froidh, 2019). In the study, railway stations were differentiated based on the size of the urban unit (town, city, large city) and the surroundings of the railway station (urban, semi-urban, peripheral). Urban stations are usually located in central points of the city, semi-urban stations in built-up areas of mostly industrial or suburban character, and peripheral stations situated on the outskirts, approximately 1-4 km from the city center. In addition to the criteria mentioned above, the literature also includes classifications based on location, population, interchange & interface, coverage, or capacity (Sheikholeslami, Langeroodi, & Karimi, 2023).

Research shows that implementing actions such as the introduction of intermediate public transport stops, resulting in improved PuT accessibility, may lead to a decrease in the car share in the modal split (Nosal & Starowicz, 2015). Importantly, the extent of changes in the modal share caused by the introduction of new railway connections in the daily commutes of workers is related to the distance of the journey to the city center. An analysis conducted for the USA indicates that for new railway stops located farther from central business districts (CBD), the number of passengers switching from cars to trains is greater than for stops opened closer to the CBD (Baum-Snow & Kahn, 2005). This study suggest that when stops are located closer to the city center, the number of passengers increases after the opening of new railway connections. However, these passengers are former bus users, not former car users. Similar conclusions regarding shifts in transportation habits from buses to trains were reached in the new Hong Kong railway line outcomes analysis (Wang et al., 2023). Jurik and Janos, in their article, apply this thesis not only to rail transport but to public transport in general, arguing that after new transport infrastructure facilities are opened, they are primarily used by passengers who were already using another form of public transport (Jurik & Janos, 2023). Therefore, in order to increase the share of trips made by public transport in the modal share, it is not sufficient to create a new railway station; it is equally important to persuade potential passengers to change their transport habits.

It is also worth emphasizing the undeniable fact of the mutual interactions between a railway stop and the spatial development of its surroundings. The implementation of Transit Oriented Development (TOD) policies when planning new railway stops allows for increased accessibility in urban areas (Tsumita et al., 2023). On the one hand, railway stops should be located in areas with high population

density (Hamacher, Liebers, Schoebel, Wagner, & Wagner, 2001). On the other hand, the opening of a new railway stop in a metropolitan area can lead to an increase in the number of residents (Tivang, 2023), employment (Salov & Semerikova, 2023) and improved reputation of the station catchment area (Brown & Werner, 2010). The establishment of a new railway station can also contribute to an increase in housing and land economic values (Rojas, 2024; Vichiensan, Wasuntarasook, Prakayaphun, Kii, & Hayashi, 2023; Yang et al., 2020). However, in certain cases, due to factors such as increased noise from railway traffic and other social factors, properties located directly next to railway stations may decrease in value (Forouhar & Van Lierop, 2021).

It is also important to note, that the increase in the number of residents around railway stations is primarily visible for urban stations and may not occur for peripheral stations located on the outskirts of cities (Adolphson & Froidh, 2019).

It should also be noted that changes in transportation habits caused by the creation of a new railway stop are directly linked to the specific railway stop's user satisfaction. The most important factors indicated in the literature include (Ibrahim, Borhan, Izzi, & Ismail, 2020): availability, accessibility, ticket offers, passenger information, travel time, customer service, comfort, safety, and corporate image. Depending on the conducted study, the weights of these factors are perceived somewhat differently by passengers.

In a study on the perception of railways in Northern Italy (Eboli & Mazzulla, 2008), the most important factors identified were those related to travel safety and security as well as punctuality and regularity. The perception of safety is particularly important for women, who generally feel more threatened than men when traveling by public transport (Ouali, Graham, Barron, & Trompet, 2020). Interestingly, however, in a study conducted in Copenhagen (Ingvardson & Nielsen, 2022), the authors emphasize that to increase the number of people using public transport, it is more important to focus on frequency and coverage rather than solely on improving the perceived safety level.

The Dutch railways NS, parallel to Maslow's pyramid, indicate that higher-order aspects such as physical comfort or positive emotions are significant to passengers only when more basic needs like ease of travel and speed are met, with safety and reliability positioned at the very bottom of the hierarchy (Van Hagen, 2015). This thesis is supported by survey research and calculations conducted for Tianjin by Wang et al. The authors (Zeng, Wang, Gao, & Wang, 2024), besides the most crucial factor, which is the sense of security, list additional factors such as the comfort level of the train station, train crowding, and journey time.

Studying the impact of launching a railway stop on travel within its area of influence, a particularly important criterion for passenger satisfaction is accessibility and the resulting differences in how potential passengers reach the railway stop. Dutch studies (Givoni & Rietveld, 2007) show that the construction of new railway stops in the case of a relatively dense railway network, may lead to an increase in the share of walking and cycling trips in the overall transport mode share. It's a result of reducing the distance from the starting point of the journey and what is important, it is usually performer at the expense of trips made by public transport.

Other authors (Midenet, Come, & Papon, 2018; La Paix, Cherchi, & Geurs, 2021) indicate that passengers might be inclined to change their mode of access to the railway stop from a car to public transport or a bicycle if appropriate amenities are provided, such as integrated scheduling, a common ticket, bicycle parking facilities or a cohesive network of safe bike paths. Contrary to that, a model created for Italy, showed that it is very hard to increase the share of active mobility in regard of trips to and from the train station, even after implementing significant infrastructural improvements (Giansoldati, Danielis, & Rotaris, 2021). Changes in transportation behavior when reaching the train station are also less likely in households with many young children (Lu, Prato, Sipe, Kimpton, & Corcoran, 2022).

It should also be noted that the choice of transportation mode to reach the railway station is directly linked to the spatial development around the railway station (Polom, Tarkowski, Puzdrakiewicz, & Abramovic, 2018). For railway stations located in areas with low population density and areas significantly distant from major traffic generators (such as airports or shopping centers), the share of pedestrian trips will be significantly lower compared to other railway stations. In such cases, in order to increase transport accessibility to the railway station, it is essential to provide efficient public transport—buses

or trams (Theerathitichaipa et al., 2023). It is particularly important, considering the fact, that the long distance between the train station and journey start or termination point may prevent passengers from using the train (Jehle, Coetzee, Buttner, Pajares, & Wulfhorst, 2022). Additionally, people living in less dense areas are usually capable of walking longer distances to train stations than residents living in inner-city areas (Sarker, Mailer, & Sikder, 2020). The literature is still not certain about the exact distance a person is willing to walk in order to use the railway station – some studies prove that it is only about 500-600 meters (Jaafar Sidek et al., 2020; Tennoy, Knapskog, & Wolday, 2022), while others consider longer distances of around 800 meters (e.g. Lahoorpoor, & Levinson, 2020; Jehle, Coetzee, Buttner, Pajares, & Wulfhorst, 2022; Pueboobpaphan, Pueboobpaphan, & Sukhotra, 2022) or even up to 1 km (Pongprasert, 2020).

In order to encourage people to use a pedestrian route, it should, among other things, pass through a safe neighborhood, have a sufficiently wide and well-lit sidewalk, be well-maintained in winter, and be as separated from car traffic as possible (Tennoy, Knapskog, & Wolday, 2022; Trolese, De Fabiis, & Coppola, 2023).

The literature review conducted highlights that there are only few studies addressing the impact of opening suburban railway stops on transportation behaviors and determining their potential influence on modal shift in details, especially in the context of railways serving commuter traffic.

3. Methodology

For the purpose of analysis, the study selected the Kraków and Łódź metropolitan areas as urbanized regions with similar characteristic features. Both agglomerations have comparable populations (around 1 million residents), the main city area within the agglomeration is similar (about 300 km²), and there is not a significant difference in population between Kraków (approximately 800,000) and Łódź (close to 700,000). The suburban rail systems in both agglomerations were launched at the same time (2014) and are based on four main routes. Beyond the provincial cities, a comparable number of municipalities fall within the reach of the suburban rail lines: 5 in the Kraków agglomeration and 8 in the Łódź agglomeration. The systems operate under their own names: the Kraków agglomeration has the Szybka Kolej Aglomeracyjna (SKA), and the Łódź agglomeration has the Łódzka Kolej Aglomeracyjna (ŁKA). In both agglomerations, rail connections within the suburban rail system are mainly operated by regional carriers: Koleje Małopolskie (KMŁ) and Łódzka Kolej Aglomeracyjna (ŁKA), although countrywide carrier Polregio also provides a portion of the transport services. Numerical analyses regarding the number of passengers served were conducted based on data obtained from the regional carriers. Polregio declined to provide their data (Ciaston-Ciulkin, Pulawska-Obiedowska, & Sobon, 2023).

The analysis focuses on six passenger exchange points in railway transport that were established or modernized during the operation of suburban railway systems in the studied agglomerations:

– in the Kraków agglomeration:
  - Kraków Bonarka railway station – modernized in 2021,
  - Kraków Grzegórzki railway stop – opened in August 2023,
  - Kraków Złocień railway stop – opened in November 2021,
  - Wieliczka Bogucice railway stop – opened in December 2014,
– in the Łódź agglomeration:
  - Pabianice Północne railway stop – opened in December 2023,
  - Zgierz Rudunki railway stop – opened in December 2023.

To examine the significance of these new railway stops on changing transport behaviors within their impact areas, the analysis included spatial accessibility analysis of the railway stops, passenger exchange analysis at the stops, and survey studies among individuals using these railway stops. This comprehensive approach aims to assess how these new or modernized stops influence commuting patterns and modal choices among commuters in the respective agglomerations.

The accessibility analysis of railway stops was conducted using QGIS3 software. The analysis utilized three isochrone levels corresponding to distances of 500, 1000, and 1500 meters from the railway stop. Pedestrian isochrones were delineated based on the OpenStreetMap road network using the OpenRouteService API. The population within each isochrone was estimated automatically using the ORS Tools plugin, which relies on open data from the european Global Human Settlement Layer (GHSL).

The passenger volume analysis at the railway stops was conducted based on vehicle occupancy survey results from 2015 and data obtained from the regional railway operators Koleje Małopolskie and Łódzka Kolej Aglomeracyjna. Using data provided by these operators at the specified stops, the average number of passengers using each train serving the railway stop was estimated for the first quarter of the station's operation and the third quarter of 2023. Based on this average and the total number of trains serving each stop, the average number of people using the stop per day was calculated.

The estimated number of residents within a 1 km radius of the railway stop's impact area and the average daily number of passengers using the railway stop allowed for the calculation of the suburban railway utilization rate. This rate is defined as the number of passengers using the railway stop per 1,000 residents within a 1 km radius of the stop's impact area.

The quantitative analysis also allowed to determine an estimated increase in the utilization of railway stops over time since their establishment. The increase in passenger volume at the railway stops in December 2023 compared to December 2021 was determined for the stops Kraków Bonarka, Kraków Złocień, and Wieliczka Bogucice. For the remaining stops, due to their shorter period of operation, the dynamics of passenger traffic growth either have not been determined or pertain to a different reference period.

To determine changes in transport behavior concerning the enhanced accessibility of railway stops, a survey in the form of direct interviews was conducted. The study targeted individuals boarding or alighting at the surveyed train stops. The general population considered for the study consisted of people making such trips. Since the surveys were conducted over a single day (May 8, 2024, in the Kraków agglomeration and May 15-16, 2024, in the Łódź agglomeration), the average daily number of individuals boarding or disembarking at the station was used as the general sample size. As a simplification, and to minimize the risk of underestimating the population due to passengers making only one trip per day, it was assumed that most individuals travel in both directions during the day. Ultimately, the estimated number of individuals using the surveyed railway stops was 2,600. A total of 475 individuals using the surveyed railway stops participated in the survey, indicating a survey error of 4% for the obtained sample size. However, despite the participation of over 20% of passengers using the stop, the stratified sample error was higher, ranging from 9% to 14% (Table 1).

In the survey, respondents answered questions regarding their travel during the survey period. The questionnaire included inquiries aimed at gathering information on several aspects, including the accessibility of railway stops (respondents answered questions regarding their arrival time at the railway stop), the mode of transportation to the railway stop, and the transport mode used before and after the railway stops in question were operational.

4. Results and discussion

4.1. Characteristics and classification of railway stations with consideration of spatial accessibility aspects

The railway stops analyzed in this article have been categorized based on the surroundings of the railway station and the type of passenger flow, with an additional type of stop identified as *office/commercial and partly residential*. This type is characterized by the occurrence of several peaks on weekdays, with the largest peak visible in the afternoon hours. This is associated with the commutes of office workers, the return of residents to their homes, and trips motivated by shopping in commercial facilities (Fig. 1). For this type of railway stop, traffic on Saturdays is high due to the opening of shopping centers, while on Sundays, it is very subdued and relatively uniform throughout the day (as shops and malls in Poland are closed on Sundays).

Tab. 1 Research sample size (Source: own elaboration)

Railway stop/station	Kraków Grzegórzki	Kraków Bonarka	Kraków Złocień	Wieliczka Bogucice	Pabianice Północne	Zgierz Rudunki	Total
Population size	1 100	440	570	130	265	80	2 585
Surveyed share of population [%]	8,2	29,9	22,9	26,6	21,9	39,5	18,4
Sampling error [%]	9,8	7,1	7,5	14,4	11,4	13,9	4,06

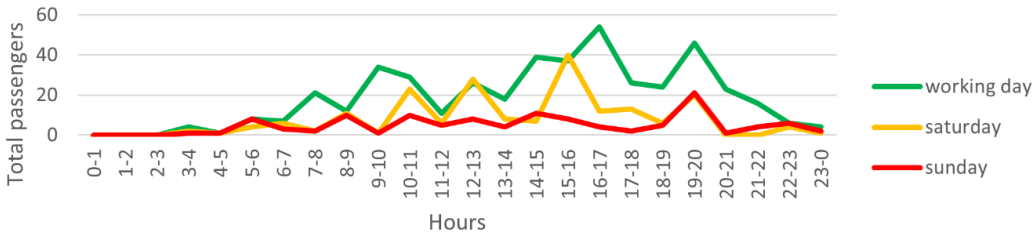

Fig. 1. Proposed office/commercial and partly residential station type typical passenger flow (Source: own elaboration based on KMŁ data)

The selected railway stations for analysis have diverse characteristics, influencing their usage differently. Three of the analyzed railway stations (Kraków Bonarka, Kraków Grzegórzki, Kraków Złocień) operate within the city that serves as the main traffic generator in the Kraków agglomeration, and they vary in terms of the area they serve.

Kraków Grzegórzki, which has been operational since August 2023, serves the downtown area characterized by intensified development directly adjacent to the station. Within a 1 km radius of the station, more than 26,000 people reside, and due to its location, it encompasses a significant part of the historic Old Town (including the Main Market Square) and numerous commercial and service facilities such as the Hala Targowa, Galeria Kazimierz, small shops, restaurants, and tourist service points typical of downtown areas. Within a walking distance not exceeding 1500 meters (approximately 15 minutes on foot), passengers can reach almost any destination within Kazimierz, Old Town, or Wesoła. The station is strategically positioned between Kraków Główny and Kraków Zabłocie railway stations. It was designed as a multimodal interchange hub integrating railway connections with the tram and bus network. The station serves trains from every line of the SKA Kraków agglomeration railway system (with 138 trains on weekdays and 129 on other days). Situated on a viaduct, the elevated railway station has municipal public transport stops located underneath.

Kraków Złocień is located in the southeast part of Kraków, on railway line 91 running from Kraków to Tarnów. Adjacent railway stops include Kraków Bieżanów in the Bieżanów district and Kokotów, situated outside Kraków's city limits, in the municipality of Wieliczka. The first of two platforms at the railway station was opened in October 2021, with the second platform in June 2022. Kraków Złocień exemplifies a railway station located near an urban area dominated by residential buildings. The northern side of the station area is densely populated with multi-family housing and industrial-commercial facilities, while the southern side features single-family residential buildings. As the walking distance to the railway station increases, its potential to serve a larger number of residents grows. Integration of the railway station with other means of transportation is currently inadequate. Generally, access to the railway station is by foot, although pedestrian infrastructure solutions are insufficient. There is a proposed project for a Park&Ride parking facility near the station, but its completion date is uncertain. Although the railway station provides connections to local municipal buses, the bus stops are located approximately 250 meters south and 500 meters north of the railway station. Currently, the railway station handles about 54 trains on weekdays, with 27 trains in each direction.

Kraków Bonarka is a railway station that underwent extensive modernization and was reopened in July 2021. It is located in the Podgórze district, south of the city center. Due to its surroundings, it serves a different purpose in passenger traffic compared to Kraków Złocień. The residential function in the adjacent area to the station is rather marginal, although the modernization of the railway station has positively impacted the development of residential investments in this area. To the east of the station, the main traffic generator is the large Bonarka City Center shopping center (92,000 m²), located approximately 1 km away from the railway station, occupying the site of former industrial plants. On the western side of the station, there is a multi-level intersection of a major road artery, which may pose a barrier for pedestrian access from the adjacent commercial and service area. The railway station serves suburban trains operating on line SKA2, which runs from

Skawina and further to Miechów. There are 68 trains operating on this line during weekdays. Nearby the railway station, there are municipal bus stops located approximately 100 and 250 meters away, but pedestrian connections between them are not satisfactory. The other analyzed three railway stations (Wieliczka Bogucice, Pabianice Północne, and Zgierz Rudunki) serve the outskirts of towns adjacent to the main cities of the agglomeration (the first with Krakow, the latter two with Łódź). They mainly serve the residents commuting to and from the main cities of the agglomeration. The areas surrounding these stations are characterized primarily by residential housing, mostly single-family homes, with the key difference being their opening dates: Wieliczka Bogucice has been operational since the launch of connections between Krakow and Wieliczka under the SKA1 line, while the railway stations in the Łódź agglomeration were established many years after the commencement of railway connections, as part of network densification.

Wieliczka Bogucice railway station is located in the north-western part of Wieliczka, adjacent to Krakow from the south-eastern side. It is situated on the outskirts of the city, surrounded by green and agricultural areas. Nearby, there are commercial and industrial facilities, with predominantly single-family and multi-family residential buildings. The station was opened in December 2014 along with the launch of the first railway connection within the SKA Kraków agglomeration railway system (currently the SKA1 line from Wieliczka Rynek Kopalnia to Krakow Lotnisko). Currently, the station serves 32 pairs of trains per day. At the time of its opening, the station served an area with little transport potential (within a 1 km radius, there were only few single-family houses). The introduction of a railway station with frequent train connections significantly increased the attractiveness of the neighboring areas for residential development. Within a decade of its opening, several dozen apartments in multi-family buildings were built in its immediate vicinity. Initially, the railway station was not integrated with any other mode of transportation, and convenient pedestrian or bicycle paths were not provided due to the low level of spatial development in the area of influence. Over time, in response to the growing demand for parking spaces, the roadside adjacent to the station was paved, creating a parking area capable of accommodating approximately 25 vehicles. On weekdays, this parking area is fully utilized by commuters. Apart from the parking spaces for cars, the station is not integrated with other modes of transport. The nearest bus stop served by Wieliczka Bus Service vehicles is approximately 900 meters away from the railway station.

Zgierz Rudunki is a newly constructed railway stop opened in December 2023 and located in the northeast part of the city of Zgierz within the Łódź metropolitan area. The station consists of a single-sided platform serving a single-track railway line. The surrounding area primarily comprises low-density residential buildings and agricultural structures. Expanding the influence area to 1000 and 1500 isochrones selected industrial facilities and some multifamily residential buildings located in the center of Zgierz are also included. It's worth noting that another railway stop (Zgierz Jaracza) is located approximately 1.2 km away from Zgierz Rudunki, providing an alternative travel option for some passengers within the catchment area. The station is accessible for persons with disabilities and is equipped with benches, shelters, voice information system, and five bicycle racks. On the eastern side of the station, there is an informal, unpaved, and unmarked car parking area. Pedestrian access to the railway platform is not very comfortable due to the lack of sidewalks along the adjacent streets. As of June 2024, the station operates with 19 pairs of trains departing, facilitating travel to nearby cities such as Łódź, Łowicz, and Głowno.

Pabianice Północne is a railway stop that, similarly to Zgierz Rudunki, opened for passengers in December 2023. The station serves the northwestern part of the city of Pabianice, located in the southern part of the Łódź metropolitan area. In the immediate vicinity of the station (up to 500 m), there is primarily low-density single-family residential housing. The station's catchment area, extending further (1000-1500 m), also includes multi-family residential buildings and commercial and public service buildings closer to the central part of the city. The station also provides access to employees working in warehouse facilities along National Road DK71. In addition to pedestrian access, the station can be reached by local bus line no. 2, which stops at the nearby Karniszewska/Lutomierska stop. The station consists of two single-sided platforms, with one platform serving trains towards Łódź and the other towards Pabianice station. Each platform is equipped

with shelters with benches, trash bins, and timetable boards. Moreover, the station and platform entrances are adapted for pedestrians and people with limited mobility, although there are local deficiencies in sidewalks and high curbs in the vicinity of the platforms. Adjacent to the railway station, there is a 5-space car parking lot, and passengers transferring from cars can also use designated parking spaces on nearby Księżycowa Street. Passengers using the railway station have access to 53 train connections per day operated by Polregio and Łódzka Kolej Aglomeracyjna (ŁKA).

For each of the analyzed railway stops, a pedestrian accessibility analysis was conducted using isochrones represented by distances of 500, 1000, and 1500 meters. The graphical results obtained (Fig. 2. a-f) allowed for determining the characteristics of the catchment area and identifying the specific type of railway station.

Table 2. Characteristics of newly-built railway stops (Source: own elaboration)

Railway stop/station		**Kraków Grzegórzki**	**Kraków Bonarka**	**Kraków Złocień**	**Wieliczka Bogucice**	**Pabianice Północne**	**Zgierz Rudunki**
		station	station	stop	stop	stop	stop
		urban	semi-urban	semi-urban	peripheral	peripheral	peripheral
Type of railway stop/station		hub and tourism commercial	office/commercial and partly residential	residential type (mixed-density)	residential type (low-density)	residential type (low-density)	residential type (low-density)
Stop/station opening		VIII.2023	VII.2021*	X.2021	XII.2014	XII.2023	XII.2023
Transport potential within walking distance [pax]	500 m	6 150	836	1 324	74	1 482	839
	1000 m	26 416	4 151	5 513	721	6 469	3 020
	1500 m	55 070	14 819	8 869	2 634	16 978	7 525
Distance to the next railway stop/station	km	[1 km; 1 km]	[1 km; 2 km]	[2 km; 1 km]	[2 km; 1 km]	[6 km; 2 km]	[2 km; 2km]
Number of trains per day	working days	138	68	54	64	53	38
	saturday, sunday	129	68	44	64	33	26
Level of integration	public transport stops	bus (50 m), tram (50 m)	bus (100/250 m)	bus (250/500 m)	bus (900 m)	bus (150 m), tram (800 m)	bus (600 m)
	P&R parkings	none	none	none	25 vehicles	5 vehicles	Wild parking ~20 vehicles
	B&R infrastructure	none	3 bike racks	none	none	10 covered bike racks	5 bike racks
	pedestrian access	accessible platforms, elevators,	accessible platforms, elevators, passenger bridge	accessible platforms, elevators,	accessible platforms	accessible platforms	accessible platforms, no sidewalk
	ticket machine	no	no	no	no	no	no
	passenger information	display screens, schedule boards	display screens, schedule boards	schedule boards	schedule boards	schedule boards	schedule boards

*modernisation

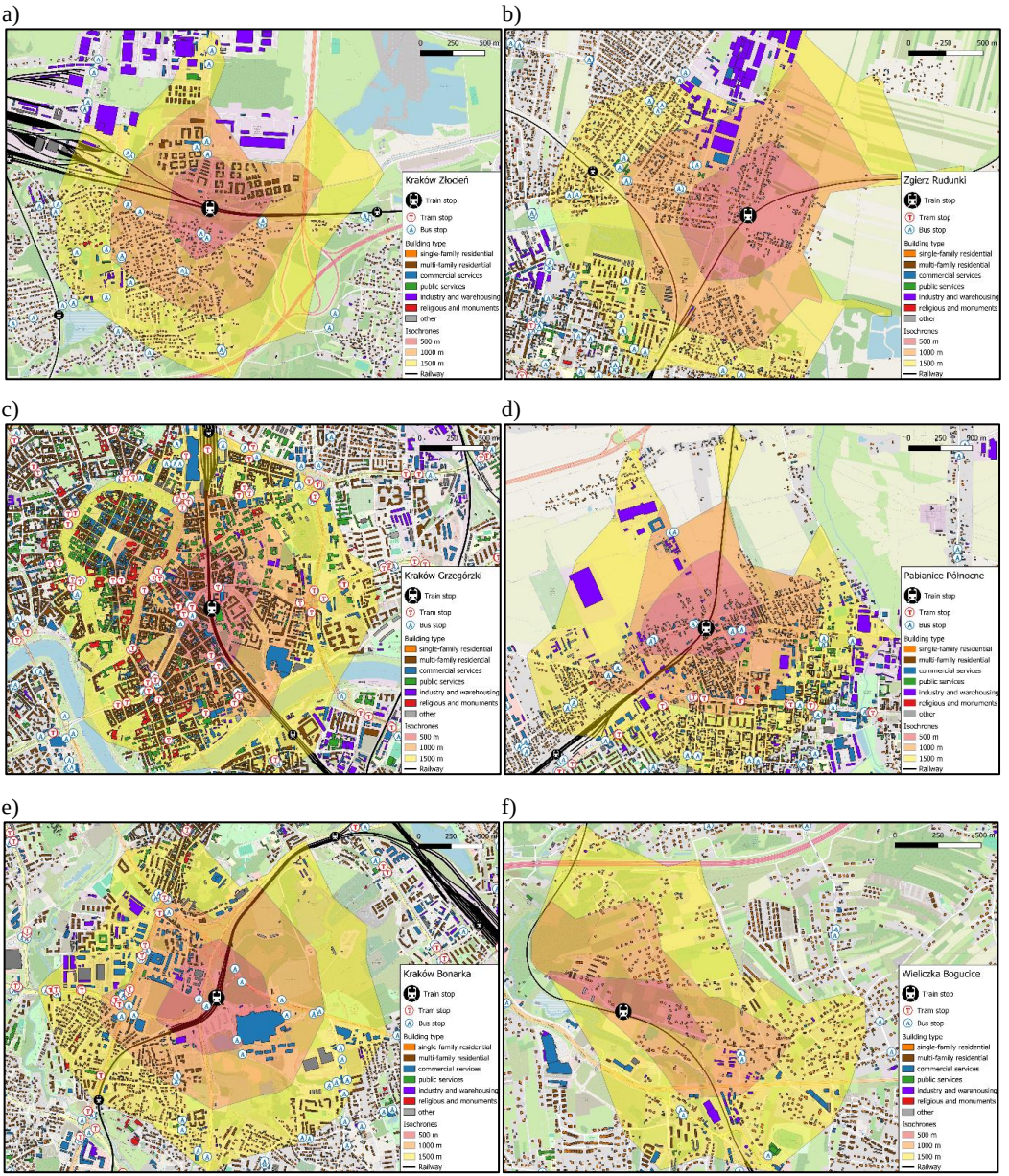

Fig. 2. Accessibility to analyzed train stops (Source: Own elaboration based on OpenStreetMap)

It's clear that passenger exchange at railway stations varies significantly, reflecting the diversity in station characteristics, integration level, and the number of trains serviced daily. The larger the transport potential of a station's catchment area, the greater the number of passengers it serves. Among the stations

analyzed within the main city of the metropolitan area (Kraków), the highest passenger exchange is observed at the station located in the city center – Kraków Grzegórzki.

During its initial month of operation, an average of about 12 passengers used the station per train, increasing to approximately 16 by the fifth month. Over a five-month period, there was an observed monthly increase in passenger traffic of nearly 7%.

The other two urban railway stops are characterized by lower passenger traffic – they are located further away from the city center and serve areas with completely different urban structures and population densities. In December 2023, Kraków Bonarka station served an average of approximately 900 passengers on weekdays, while Kraków Złocień station had over 1,100 passengers. Over the two-year period of their operation, the number of passengers increased several times:

– For Kraków Bonarka station, there was an over 4-fold increase, resulting in more than a 6% average monthly growth in passengers over the 2-year period,
– For Kraków Złocień station, there was nearly a 3-fold increase, resulting in over a 4% average monthly growth in passengers over the 2-year period.

It is worth noting the relationship between the number of trains serving the stations and the number of passengers. In both cases, the number of trains serving them is at least half of that at Kraków Grzegórzki: 68 trains per day at Kraków Bonarka and 54 trains per day at Kraków Złocień. However, the average number of passengers per train stop is nearly twice as high at Kraków Złocień (18-20 people) compared to Kraków Bonarka (11-13 people). Despite fewer train frequencies, Kraków Złocień experiences higher traffic due to the specific area it serves. The immediate vicinity of the station includes one of Kraków's residential areas, generating a significant number of obligatory journeys. Kraków Bonarka, despite being closer to the city center, has lower transport potential.

For stations serving the outskirts of satellite cities, their usage is much lower – on weekdays, each station sees no more than a few hundred passengers per day, directly correlated with the spatial development of their influence area. These are areas characterized by dispersed mainly residential buildings and a significant potential for regular obligatory travels. In the case of stations launched in the Łódź agglomeration, due to their short operational period (since December 2023), it is difficult to determine the dynamics of passenger traffic growth. However, the example of Wieliczka Bogucice station demonstrates that launching a railway station in an area with even low transport potential results in an increase in rail journeys. After the Wieliczka Bogucice station was opened, the average daily passenger exchange did not exceed 50 people, whereas a decade later, more than 6 times as many passengers use the station.The importance of the analysed railway stations in serving their catchment areas (1 km radius) was also assessed based on a indicator illustrating the number of passengers using the railway station per 1,000 residents living within the influence area. The value of this indicator for Kraków Złocień and Kraków Bonarka stations is comparable (196 and 213 passengers/1,000 residents respectively), as is the period of their operation (June and October 2021 respectively). A significantly lower value of the indicator characterizes Kraków Grzegórzki station (84 passengers/1,000 residents), although considering its short operating time (since August 2023) and the high growth dynamics of serviced passengers (6.7% per month), an increase in this indicator to three-digit values can be expected. Two stations in the Łódź agglomeration also have a low indicator of the number of trips per resident: Pabianice Północne (82) and Zgierz Rudunki (50), which also results from their short operating period (launched in December 2023). The highest indicator by far was observed at Wieliczka Bogucice station (over 400 passengers/1,000 residents), explained by its long operating time, low population density in the area, and integration with individual transport. The establishment of a designated parking area for cars increases the spatial accessibility of the station and generates additional passenger traffic from residents living in the influence area beyond 1 km radius.

4.2. Analysis of current behaviors of railway passengers using new railway stations

4.2.1.Transport modes for reaching the stop

Selected railway stations and stops examined in the study are mostly characterized by a low level of integration with other modes of transport, especially individual transport. This affects their accessibility level. In five out of six studied stations, at least two out of three passengers arrive at the station by

walking. The station with the lowest percentage of passengers arriving by walking Wieliczka Bogucice. It is the only analyzed station where passengers arrive using a more diverse range of transportation methods, stemming from solutions integrating the railway with other modes of transport. Although such integration was not initially planned during the construction of the railway station, over time, an adjacent road was paved and marked, allowing for vehicle parking. The possibility to park vehicles, especially without charges, along with the location of the station on the outskirts of the agglomeration in an area with low-density development, contributes to a significant reliance on individual transport, which is higher compared to other railway stations. Nearly one in four users of the station travels to the train by car, with three-quarters of this group driving themselves and the remainder being passengers, driven by someone else.

The significantly lower share of cars used for commuting to the station is worth noting in case of the two youngest railway stops in the Łódź agglomeration: Zgierz Rudunki and Pabianice Północne. For the first of them, the share of individual transport in commuting to the station is 14%, while for the latter, this share is twice as low. Both stations, like Wieliczka Bogucice, serve passengers commuting to the agglomeration's capital from neighboring towns. However, in the cities where they are located, they do not have a leading role in service, although Pabianice Północne serves an area with significantly higher population density and higher residential buildings compared to the other two. This aspect may contribute to the lower share of individual transport in commuting to these stations compared to Zgierz Rudunki and Wieliczka Bogucice (Fig.3).

Considering the characteristics of the catchment areas of the Wieliczka Bogucice and Zgierz Rudunki stations, as well as passenger transport behaviors, a similar development direction for the Zgierz station as in Wieliczka can be expected. Desired solutions will include safe parking facilities for cars and bicycles, and the immediate vicinity may become attractive for residential investments.

Table 3. Analysis of newly-built railway stops utilization (Source:Own elaboration based on data provided by railway carriers KMŁ and ŁKA)

Railway station/stop		**Kraków Grzegórzki**	**Kraków Bonarka**	**Kraków Złocień**	**Wieliczka Bogucice**	**Pabianice Północne**	**Zgierz Rudunki**
Average passenger exchange volume for 1 train	First quarter since opening	12-14	4-6	7-9	1-1,5	9-10	3-4
	Q4 2023	14-16	11-13	18-20	3-4	9-10	3-4
Dynamics of the average passenger exchange growth for trains stopping at the station in XII.2023	Reference month	VIII.2023	XII.2021	XII.2021	XII.2021	Not applicable	Not applicable
	Reference month = 100%	128%	437%	267%	141%	Not applicable	Not applicable
Average monthly passenger volume growth compared to the reference month		6,7%	6,3%	4,2%	1,4%	Not applicable	Not applicable
Estimated total volume of passengers per day	XII.2023/ IV.2024*	2 200	890	1 100	320	530*	150*
Average numer of journeys for 1000 inhabitants within 1 km isochrone from		84	213	196	444	82	50

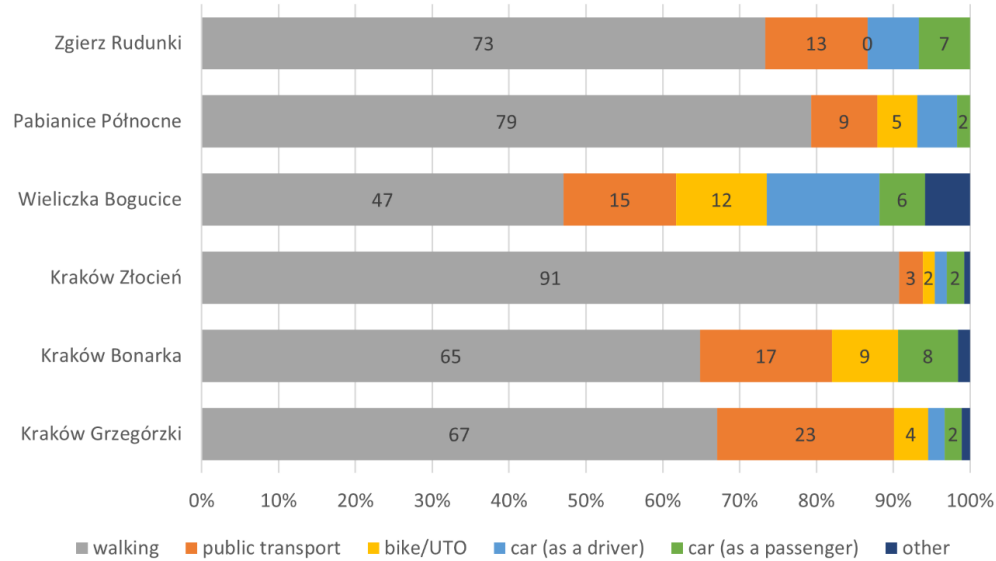

Fig. 3. Transport modes used by passengers in order to get to the railway station/stop (Source: Own elaboration)

In contrast to the behavior observed at stations located in smaller urban centers, significantly different patterns are observed at stations within Krakow, the largest urban generator in the metropolitan area. At these Krakow-based stations, individual transport to the stations is minimal, especially when considering the need to park a car (driving oneself). Only at Krakow Bonarka station, located in an area with intensive commercial and service-oriented development but not directly adjacent to the station, is there an increase in the share of passengers being dropped off by other drivers (8%). Limited availability of parking spaces around the city-based stations or the necessity of paying for them entirely marginalizes individual transport in commuting to railway stations. Instead, public transport serves as the primary alternative for commuters in these areas.

Within the downtown (Krakow) exists the highest accessibility level both spatially and temporally of public transportation (buses/trams) throughout the entire metropolitan area, which translates into its significant importance for commuting to railway stations. The highest share of public transport usage to reach the railway station is observed at Krakow Grzegórzki station, owing to its conception as a central interchange hub facilitating seamless transfers between trains, buses, and trams. Nearly one-fourth of respondents declare using public transport to travel to/from this railway station. With the passage of time and continued operation of the station, the share of integrated journeys combining train travel with urban public transport at this interchange hub is likely to increase.

In the case of Kraków Bonarka station, public transportation plays a lesser role. On average, every sixth respondent states that they reach the station using local public transport vehicles, which may be linked to the lower accessibility level of bus and tram stops. Respondents using Kraków Złocień declare an entirely marginal share of reaching the railway station by bus/tram, and indeed this stop is characterized by very low integration with other modes of public transportation.

In the case of railway stations located in peripheral areas in neighboring towns, public transportation also plays a significant role. The share of this mode of transport in reaching the stops in Zgierz, Pabianice, and Wieliczka ranges from 9% to 13%.

4.2.2.Time to reach the railway station

The average time to reach the railway station is related to the type of the area it serves. It is noteworthy that the travel time to railway stations serving satellite towns (Wieliczka Bogucice, Zgierz Rudunki,

Pabianice Północne) is quite short. For the stations examined, at least 70% of respondents do not need more than 10 minutes to reach the train, and almost all respondents reach the station in no more than 20 minutes (Fig. 4).

Railway stations located within the main city of the agglomeration exhibit significantly different travel time accessibility. In their case, longer than 10-minute travel times to the railway stations are more frequently observed, which is also associated with a higher use of public transport for commuting, as well as the level of integration of the station with other modes of transport and the distance from potential origins and destinations of travel. Considering the stations located in Krakow, it is evident that significantly more passengers arrive at Kraków Grzegórzki station within a short, not exceeding 10-minute time frame (nearly 60%). This is partly due to the station's good integration with bus and tram connections and its proximity to dense urban development. Within a 500-meter walking radius to the station, over 7 times more people reside compared to a similar radius around Kraków Bonarka station and nearly 5 times more than Kraków Złocień station. For the latter two stations, the walking time to reach the station varies, with the majority of passengers needing more than 20 minutes (over 60%). The density of urban development around these stations significantly increases with distance.

4.3. Changes in the usage of other transport mode after the opening of new railway station

The increase in passenger volume at railway stations may be result from the enhanced mobility of residents, emergence of new travel origins/destinations, or shifts in the modes of transportation used. For newly established railway stations, passengers adapt their transport behaviors by switching from previous modes of transport to trains. Survey studies have identified changes in transport behaviors among passengers using these surveyed railway stations. Data presented in Fig. 5 indicate significant differences between stations. Specifically, for railway stations launched in the main city of the agglomeration, their establishment largely contributes to a migration of passengers from other means of public transportation (from 45% to 62%). Transitioning from personal vehicles to train connections is observed much less frequently. Instead, some passengers, due to the new station, do not change their transportation habits but simply cease using another railway station in favor of the newly-built one.

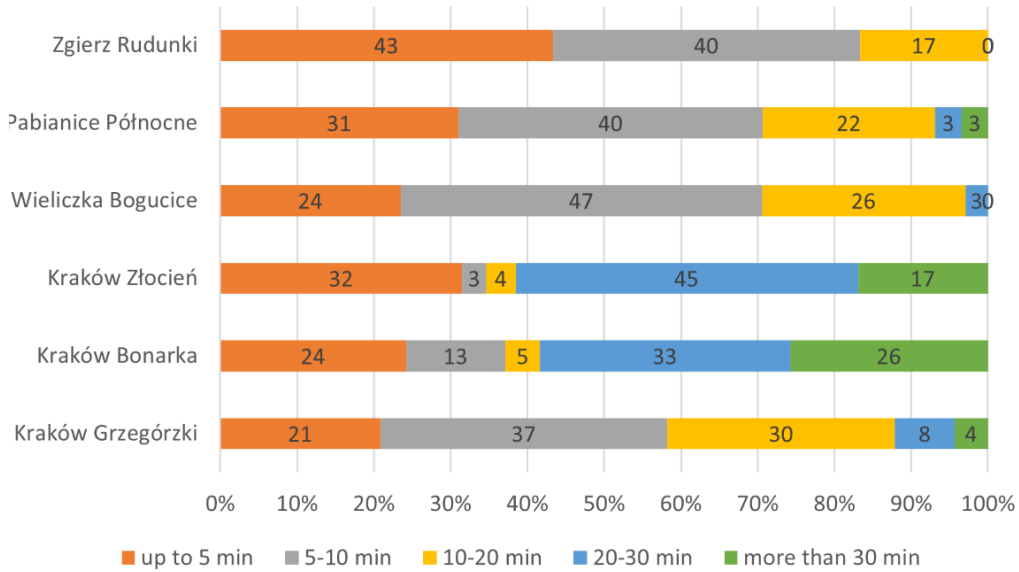

Fig. 4. Time required to reach the railway station/stop by passengers (Source: Own elaboration)

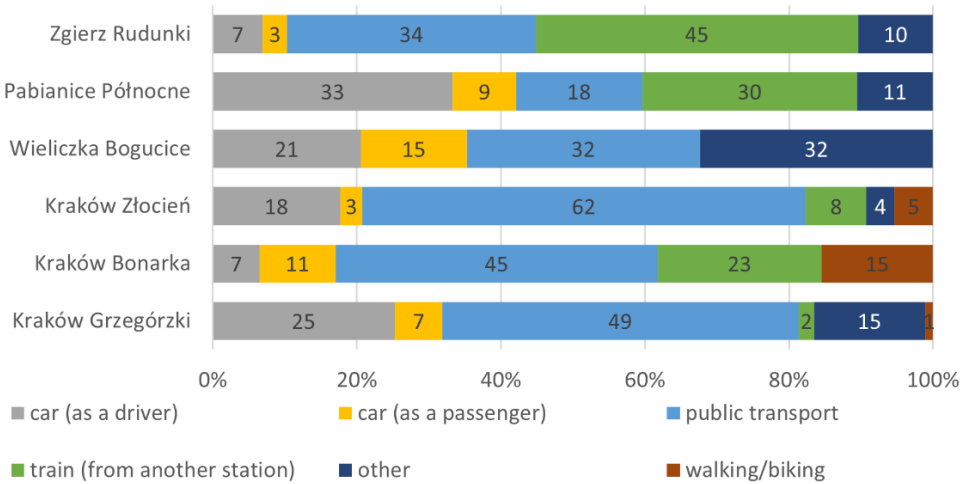

Fig. 5 Transport modes chosen by present railway passengers before opening of particular railway stops (Source: Own elaboration)

For railway stations located on the outskirts of satellite towns, it is difficult to identify consistent patterns regarding changes in transport behaviors, except that their establishment has led to a reduced outflow of passengers from public transportation in favor of railway connections (from 18% to 34%). This is closely related to poorer public transport services provision in the outskirts of the agglomeration and the higher competitiveness of individual transport compared to larger cities. Analyzed railway stations situated in satellite towns, due to different times of establishment and periods of operation, have influenced transport behavior changes differently.

Pabianice Północne and Zgierz Rudunki were launched in December 2024, a decade after the inauguration of the first railway connections in the agglomeration, essentially complementing existing railway stations. This resulted in 30% of users of Pabianice Północne and 45% of users of Zgierz Rudunki previously using railway connections, but from a station with poorer time accessibility. Regarding users of Wieliczka Bogucice, nearly one-third declare that they did not previously undertake such journeys, which is due to the significantly longer period of operation of the station. During its operation, the spatial development of the station's area has already changed: many multi-family residential buildings have been built, contributing to increased travel due to residing in adjacent areas connected to the station.

5. Discussion and conslusions

It is difficult to unequivocally determine the extent of the impact of establishing new railway stations on the particular travel behaviors of people in agglomerations. However, it is undeniable that their introduction leads to an increase in the number of people using railway connections. In the context of continuous growth in road congestion and its associated effects, this development holds significant importance. The increase in railway users is confirmed by numerical data on passenger exchange at new railway stations, regardless of their specific character and the transport potential of the serviced area.

The article analyzed changes in transport behaviors at various railway stations characterized by diverse features. The analysis included stations located in

different parts of the agglomeration (city center, outskirts, outside the main city of the agglomeration), adjacent to areas with varied spatial development (downtown areas, predominantly residential areas, commercial-service areas), and differing levels of integration with other transport modes (non- or poorly integrated, integrated with public mass transit, integrated with individual transport). Additionally, the period of their operation also varied (from several months to 10 years).

The conducted analysis of passenger traffic volume at railway stations, as well as passenger opinions expressed in the survey, proves that the establishment of new railway stations on the suburban railway systems undoubtedly contributes to an increase in passenger traffic. The limited number of objects included in the study does not allow for unequivocal conclusions regarding the expected increase in transportation, but certainly, in the first two years following their launch, a monthly average increase of 4-6% can be anticipated.

The mode of accessing newly established railway stations is influenced by their integration with other transportation modes, although pedestrian access remains predominant (ranging from 47% to 91%). The share of pedestrian access decreases with increased integration levels. For railway stations located in close proximity to tram and bus stops (especially those in the main city of the agglomeration), the role of public transport in accessing railway stations increases, which confirms the thesis about the benefits of investing in public transport integrated with railway stops (Theerathitichaipa et al., 2023). When parking spaces are designated near the railway station or at least a place allowing car parking is available nearby, the proportion of passengers arriving by car to the railway station increases. A higher proportion of individual transport for accessing railway stations is observed for stations located on the outskirts of the agglomeration.

Typically, for railway stations located in the city center (such as Kraków Grzegórzki) and on the outskirts of the agglomeration, the time to reach the platform is within 10 minutes. In the case of stations situated in the central part of the agglomeration but outside the city center (like Kraków Bonarka and Kraków Złocień), there is an increase in the proportion of passengers who reach the railway station in more than 10 minutes, which expands the perspective on acceptable walking times to stations, currently described in the literature (Sarker, Mailer, & Sikder, 2020), with additional insights regarding semi-urban areas.

The change in transport behavior following the establishment of a new railway station is closely linked to the timing of its opening and its location. Stations launched in densely populated residential areas with a dense network of public transport and high frequency of vehicle services (like in Kraków) significantly influence the shift from using public transport to railway connections, which aligns with the results of similar studies conducted by other authors in the past (Baum-Snow & Kahn, 2005; Wang et al., 2023; Jurik & Janos, 2023). On the other hand, stations located on the outskirts of the agglomeration, characterized by dispersed residential development and low temporal and spatial availability of public transport, often lead to a preference for using private cars. The timing of station openings also plays a crucial role. When railway stations are introduced as expansions to existing ones, a significant portion of passengers are likely individuals who previously used trains but commenced or concluded their journeys at different stations. This scenario was observed, for example, with stations like Zgierz Rudunki and Pabianice Północne.

The presented surveys were conducted mainly among current rail passengers, so on their basis it is difficult to determine the modal split changes. However, it should still be expected that particular part of new rail passengers will be former car users and the modal split in the area of impact may be reduced in share of cars by several percent (Ciaston-Ciulkin, Pulawska-Obiedowska, & Trzebunia, 2024). Giving up cars in favor of the train was confirmed in the presented studies by 10-42% of passengers. These numbers concern thus various journeys, both obligatory and non-obligatory, but these values are still optimistic and confirm the justification for supplementing agglomeration railway systems with new stops, as this may contribute to a change in modal split. This change may not be noticeable or diametrically opposed, considering the usually considered large scale of the agglomeration as a whole, but on individual corridors and on a micro scale it may have a very positive impact on the traffic situation and change the quality of travel.

The development of a new railway station undoubtedly plays a significant role in creation of new patterns of travel behaviours. Increasing station

accessibility across different areas of the agglomeration should be accompanied by improvements in transport service offerings, such as train frequency, ensuring punctuality and facilitating seamless transfers to other modes of transport through integrated ticketing, schedules, information, and infrastructure. Particularly, the integration of infrastructure can be crucial in attracting users of individual transport, such as providing nearby parking facilities at railway stations. An increasingly desirable solution in the field of integration with the railway is the creation of dedicated bus lines in peripheral areas with lower population density, the launch of which may be crucial for increasing the attendance at the the stop. The introducing of a railway stop may also be a strong driving force for the development of housing or services in a given area, however the effects in this area may be seen only in several years. Moreover, effective promotional efforts can contribute to convincing users of other transport modes, who often justify their choice of transportation mode based on their habits.

To summarize, the key conclusions drawn from this work are:

- Supplementing agglomeration railway systems with new stops, may contribute to a change in modal split;
- The change in transport behavior following the establishment of a new railway stop is closely linked to the timing of its opening and its location;
- The way passengers reach the railway stop depends on its integration level as well as its location relative to the city center;
- The most common rail passengers are former users of other means of public transport, however, the pattern of giving up cars in favor of the train was also confirmed;
- In the first two years following the launch of a new stop, a monthly average passenger number increase of 4 to 6% can be anticipated.

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