

Public transport accessibility to upper secondary schools measured by the potential quotient: The case of Kraków

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Abstract

The spatial differences in public transport accessibility to upper secondary schools are examined in this article, using the potential accessibility model, and based on the example of the city of Kraków. In order to achieve this goal, the potential quotient index has been used, taking into account both the demand for educational services operationalised with the population aged 15–19, and the supply of services depicted by the supply of places for pupils in different types of upper secondary school. A supplementary objective is to present recommendations for transport and educational policy implemented in the city in the context of potential locations of new upper secondary schools based on, among other parameters, the mean centre of the potential accessibility distribution and the potential accessibility dispersion index. We conclude that to better balance access to different types of schools throughout the city in the future, a new location for a general upper secondary school could be considered in the southern or eastern parts of Kraków.

Keywords: Potential accessibility, school accessibility, potential quotient, accessibility dispersion, Kraków, Poland

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1. Introduction

Access to services of general interest, including access to educational services at various levels of education, has been an issue analysed by researchers around the world in a variety of contexts. Some authors refer to the concept of social justice which is invoked as a basis for creating broad and equal access to education, including equal access in spatial terms (Cave and Chester, 1981; Pacione, 1989). Spatial variation in the demand for and the supply of education services, measured by the potential model, enables one to produce recommendations concerning possible new locations for schools (Department for Transport, 2005). This is particularly important for upper secondary schools which have neither a local (primary schools) nor regional (universities) catchment area. The catchment area for upper secondary schools is mainly the city itself, possibly extended to its immediate vicinity (Guzik, 2003a; Walaszek, 2016; GUS, 2018).

The relatively small number of accessibility studies concerning access to medium-level education facilities could be the result of scientists showing little interest in the pre-working age group. This group is already independent and does not need to be escorted, but it is still outside

the labour market. At least, in the countries and regions of Central and Eastern Europe, which have similarly shaped population pyramids, there are only a few valuable exceptions in relation to analyses of accessibility to schools (Guzik, 2003a, 2003b; Walaszek, 2006; Biosca, Spiekermann and Stępnia, 2013; Zelinsky and Kubak, 2014; Kučerová, Bláha and Kučera, 2015). There is, then a certain research gap in this field of research in relation to this part of the continent. The result of insufficient accessibility research is that recommendations for school locations at city level are usually implemented in an intuitive way, as proposals by local communities to city authorities demanding the construction of educational facilities. Nevertheless, this is usually related to a lower level of the education system, i.e. primary schools. In the case of upper secondary schools, new school facilities are created for various reasons, including the development of new housing estates, an influx of young migrant families, in particular in Western Europe. In Poland there were educational reforms, after which new upper secondary schools were created in Kraków, the city under examination in this study.

The main goal of the paper is to analyse the spatial differences in public transport accessibility to upper

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secondary schools using the potential accessibility model. In order to achieve this goal, the potential quotient index has been used, taking into account both the demand for educational services operationalised with the population aged 15–19 and the supply of services represented by the supply of places for pupils in different types of upper secondary school in the city of Kraków. A supplementary objective is to present recommendations for the transport and education policy adopted in the city in the context of potential locations for new upper secondary schools based, among other parameters, on the mean centre of the potential accessibility distribution and the potential accessibility dispersion index.

The novelty of this paper lies in the use of the potential quotient index, the mean centre of public transport accessibility distribution and the potential accessibility dispersion index as potential tools for planners concerning decisions on possible locations for new upper secondary schools of a particular type in the city in a period of demographic change.

The paper is made up of six sections. The second section presents a survey of literature on methods of measuring the accessibility of educational services. In the third section we describe our study area. The fourth section is devoted to the detailed methodology we use in the paper. In the fifth section we discuss the results and in the sixth section conclusions are drawn.

2. Methods of measurement of the accessibility of educational services

It is very difficult to identify an approach to accessibility which is the most appropriate from among the range of possibilities available. As Gould (1969, p. 64) indicates: "Accessibility... is a slippery notion... one of those common terms that everyone uses until faced with the problem of defining and measuring it". Despite the lack of a single definition, the concept of accessibility has been developed for many decades, and researchers, depending on the purpose of their projects, have proposed different approaches to it (Geurs and van Wee, 2004). Johnston, Gregory and Smith (1994) formulate the definition of accessibility as "the ease with which people can reach desired activity sites". They also propose three elements that should be included in accessibility analysis. In relation to the topic of this paper, these are: (1) the location of the point from which the accessibility is measured, usually places of residence; (2) the characteristics of the transport system, for example the public transport system; and (3) the location of the activities for which this accessibility is measured, for example secondary schools.

Usually the concept of transport accessibility is used in research and practice to support spatial and transport planning processes by evaluating development strategies at various scales, including Transit Oriented Development scenarios (Geurs, Zondag, de Jong and de Bok, 2010; Litman, 2008; Gulhan, Ceylan, Özuysal and Ceylan, 2013; Qviström, 2015), as well as supporting policies to guarantee high-quality public services (Stepniak, Pritchard, Geurs and Goliszek, 2017; Stepniak and Rosik, 2016). More recent research projects use accessibility in studies of the relationship between transport, social exclusion and other aspects of equity in transport (Tsou, Hung and Chang, 2005; van Wee and Geurs, 2011; Lucas, 2012; Martens, 2012; Pritchard, Moura, Silva and Martinez, 2014; Manaugh,

Badami and El-Geneidy, 2015; Stepniak and Goliszek, 2017). Some authors have also applied the concept of accessibility to express and describe relationships between urban structure and transport behaviour (Scott and Horner, 2008; Szarata, 2013).

On the basis of a literature survey (Geurs and van Eck, 2001), one can identify different groups of methods of accessibility measurement:

1. infrastructure-based accessibility measures, using infrastructure development indicators, such as the quantity and quality of infrastructure;
2. distance-based accessibility measures (travel-cost accessibility), i.e. accessibility measured by the physical, temporal or economic distance to a set of destinations;
3. isochronic-based accessibility measures (cumulative accessibility), i.e. accessibility measured by determining a set of destinations accessible within a specific distance, time, cost or effort;
4. person-based accessibility measures, analysing accessibility at the individual level; and
5. potential-based accessibility measures, which is the most popular method and the one used in this paper.

2.1 Potential accessibility

Modelling of potential accessibility has been well known since the work of Hansen (1959), who was a forerunner in this field and who defined accessibility as the "potential of opportunities for interaction". In general, potential accessibility is measured by the number of activities (opportunities) reachable within a certain distance, time or cost. The closer and greater the opportunity, the more it contributes to accessibility. The potential model is very sensitive to the particular distance decay function that is used (see Stepniak and Rosik, 2018; Rosik, Pomianowski, Komornicki, Goliszek, et al., 2020; and Goliszek, Połom and Duma, 2020).

Potential accessibility is described by the general formula:

$$A_i = \sum_j O_j F(t_{ij}) \quad (1)$$

where A_i = potential accessibility of transport zone i ; O_j = opportunity (attractiveness) of transport zone j ; $F(t_{ij})$ = distance decay function; and t_{ij} = travel time between transport zones i and j .

2.2 Accessibility components

Geurs and Van Wee (2004, p. 128) defined accessibility as "the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)." Therefore, one can select four components affecting the level of accessibility, which are transport, land-use, temporal and individual factors (Geurs and van Eck, 2001; Geurs and van Wee, 2004). Assuming that the attractiveness of the travel destination is measured by the number of places in secondary schools, the four accessibility components have the following characteristics described in the last column in Table 1.

Any changes in the assumptions lying behind the components mentioned in Table 1 can significantly affect the results of accessibility analyses. In the case of the transport component and public transport, one can take into account many factors determining the functioning of public transport – related both to the linear and point infrastructure,

Accessibility component	Characteristics	Access to educational services, in particular upper secondary schools – selected characteristics
Transport	<p>Connected to the transport system, which provides the user with the option of travelling between the origin and the destination using specific means of transport. It can be expressed by the:</p> <p>(1) total travel time (including travel time, waiting time and parking time), cost and effort (e.g. reliability, comfort level, risk of accidents) as elements of the distance decay function;</p> <p>(2) supply of the transport system including infrastructure, frequency, location of stops and tariffs, as well as demand created by the users of individual and public transport.</p>	<p>Public transport as the dominant means of transport.</p> <p>High value assigned to travel time as a nuisance factor by young people. Significantly lower importance of cost (pupils usually use discounted tickets) and comfort.</p> <p>A clear indication of accessibility as one of the most important factors and criteria for selection of the facility.</p>
Land-use	<p>The land use component reflects the land-use system, including the spatial distribution of opportunities (Geurs and van Wee, 2004) and is related both to the supply of opportunities and their location, as well as the demand for these opportunities created in the location of origin (e.g. residential areas). This component can be reflected by juxtaposing supply and demand, then the effects of competition are mapped (van Wee, Hagoort and Annema, 2001).</p>	<p>Accessibility is conditioned by changes in city structure and the demographic development of individual districts.</p> <p>Spatial variation in supply and demand is a prerequisite for the location of potential new facilities.</p>
Temporal	<p>This is related to time constraints, i.e. the level of accessibility depending on the time of day or week, or the time in which users perform certain activities.</p>	<p>Participation in school activities, usually at certain times of the day.</p> <p>A clear morning and afternoon peak.</p>
Individual	<p>Illustrating individual users or groups of people in the context of their needs, abilities and other socio-economic determinants (such as age, income, education level). These features have a significant impact on transport users and their choices (e.g. possession of a car, driving licence, skills and education in finding a school or a job in the vicinity of one's place of residence, etc.).</p>	<p>A clearly defined age of travellers: 15–19 years.</p> <p>Frequent lack of possession of a driving licence, which determines a very large share of the usage of public transport in this age group.</p>

Tab. 1: The four components of accessibility with selected characteristics relating to access to upper secondary schools. Source: authors' conceptualisation

rolling stock and quality features of the transport service. Among all the travel destinations (land-use component) for which accessibility analyses are carried out, the most common are jobs (e.g. Geurs and van Eck, 2001; Cheng and Bartolini, 2013; Östh, Lyhagen and Reggiani, 2016), shopping locations (e.g. Widener, Farber, Neutens and Horner, 2013; Pashkevich and Puławska, 2016; Niedzielski and Kucharski, 2019), health care facilities (e.g. Goddard and Smith, 2001; McGrail, 2012), and other facilities related to leisure or entertainment (Scott and Horner, 2008; Dony, Delmelle and Delmelle, 2015). Some of the accessibility studies also take into account different educational facilities (see Tab. 2).

In general, the concept of the accessibility of education was used in a dynamic way to identify spatial variation in the accessibility of education within the special context of transition in post-socialist countries (Guzik, 2003a, 2003b; Walaszek, 2006; Kučerová, Bláha and Kučera, 2015; Stępnia, Pritchard, Geurs and Goliszek, 2017). Different methods have been applied in determining the accessibility of schools, including competition effects, among them the two-step floating catchment area (hereinafter '2SFCA'), location quotient, and potential quotient. Most of the works emphasise the role of access to schools in making decisions about their choice. Accessibility, understood as proximity to place of residence, is one of most frequently mentioned aspects taken into consideration during the selection of secondary schools (GUS, 2013; Walaszek, 2006). More recent work on educational accessibility also focuses on

equity issues, and combines the spatial pattern of schools together with socio-demographic and economic variables in order to assess ongoing policies considering centralisation or other changes to the educational system (Thelin and Nedomysl, 2015; Gao, He, Liu, Zhang, Wang and Cai, 2016; Lee and Lubinski, 2017; Moreno-Monroy, Lovelace and Ramos, 2018; Ye, Zhu, Yang and Fu, 2018).

2.3 Potential quotient (PQ)

The most general form of the school accessibility model is represented by the potential model with the inclusion of the competitiveness factor. As Geurs and van Eck (2001) point out, the effects of competition on opportunities may be incorporated in an accessibility model by dividing the supply potential by the demand potential. Therefore, the indicator can be interpreted as the distribution of potential for satisfying demands as a function of the intensity of these demands (Czyż, 2002). The PQ is a variable with a continuous spatial distribution (Czyż, 2002), allowing for visual 'smoothing' of differences in the distribution of opportunities between neighbouring regions. PQ solves many problems which arise when the potential measure is employed (e.g. values at the edges of the study area or the level of friction quotient, etc. because in PQ they are being reduced). The indicator is particularly useful for estimating the accessibility of job opportunities (Weibull, 1976) or general practitioners (Knox, 1978). Nevertheless, it can also be used for modelling accessibility to secondary schools

Author(s)	Case study	Type of school	Research goal	Methods
Williams and Wang (2014)	Metropolitan area White flight, Baton Rouge Metropolitan Statistical Area, Louisiana, USA	High schools	Verification of differences in the level of accessibility of high schools in the metropolitan area.	Dynamic analysis using the 2SFCA method
Theelin and Niedomysl (2015)	Halmstad Region, Sweden	Upper secondary schools	Investigation of the factors that affect choices about which school to attend in order to verify policymakers' belief that academic quality is the only factor that influences students' choices.	Empirical survey study, regression analysis
Kučerová, Bláha and Kučera (2015)	Two rural regions (Turnov and Zábřeh districts), Czech Republic	Primary schools	Investigation of the impact of development in the primary school sector in the context of educational policy and management in the Czech Republic.	Catchment area analysis, flow analysis
Gao, He, Liu, Zhang, Wang and Cai (2016)	2873 counties (statistical units), China	Compulsory schools: primary and secondary	Analysis of the inequality of compulsory education from the perspective of imbalanced spatial distribution.	Proximity, cluster analysis, spatial pattern analysis, cold/hot spot analysis
Moreno-Monroy, Lovelace and Ramos (2018)	Sao Paulo Metropolitan region, Brazil	Secondary schools	Investigation of spatial equity in the provision of public schools together with affordable public transport. Assessment of the current policy of centralisation of public secondary education system.	Cumulative opportunities with competition
Guzik (2003a)	Małopolska voivodeship (including its capital Krakow), Poland	Secondary schools	Dynamic analysis of accessibility to secondary schools in Poland and the Małopolska voivodship in the years of 1950–1998. Verification of the impact of accessibility to education facilities on the education level of residents.	Proximity, percentage of population, potential quotient
Walaszek (2006)	Poznan agglomeration, Poland	Primary, secondary and upper secondary schools	Identification of spatial structure and selected elements of the school network in the Poznań agglomeration.	The location quotient was used in order to determine the ratio of demand to supply on the educational market
Ye, Zhu, Yang and Fu (2018)	Guangzhou, China	Secondary schools	Spatial patterns of secondary schools and disparities in school accessibility among different social groups at the neighbourhood level.	2SFCA
Lee and Lubienski (2017)	Chicago, USA	Public primary schools	Answering the research questions: how school closures pursued in 2013, impact on changes to a student's access to schools and how these changes are related to community socio-economic characteristics.	The change in accessibility is compared with density maps
Stępiak, Wiśniewski, Goliśzek and Marcińczak (2017)	Analysis based on address data aggregated to municipalities, Poland	Primary, secondary and upper secondary schools	Identification of the spatial variation in the level of a range of public services, including schools.	2SFCA; spatial concentration of high and low levels of accessibility using Local Statistics, Getis-Ord G

Tab. 2: Review of studies on the accessibility of educational facilities
Source: authors' compilation

(Guzik, 2003a, 2003b). In this case the number of pupils/students produces an educational (supply) potential (E_i) and the number of school-age individuals produces a population (demand) potential (P_i). The form of the equation is as follows:

$$A_i = \frac{D_i F(t_{ii}) + \sum_j^n D_j F(t_{ij})}{O_i F(t_{ii}) + \sum_j^n O_j F(t_{ij})} = \frac{E_i}{P_i} \quad (2)$$

where D_i, D_j = the number of pupils in schools located in the regions i, j ; O_i, O_j = the number of school-age individuals in the regions i, j ; t_{ii} = internal travel time; t_{ij} = travel time between i and j transport zones.

2.4 Potential Accessibility Dispersion (PAD)

The impact on spatial inequality is measured using the Potential Accessibility Dispersion (PAD) index, which takes into account the standard deviation of the potential accessibility values across all transport zones and the mean accessibility level, using the population aged 15–19 as the weighting variable (for details see López, Gutiérrez and Gómez, 2008; Ortega, López and Monzón, 2012; Stepniak and Rosik, 2016). The lower the PAD values, the less polarised is the study area in terms of accessibility distribution.

2.5 Mean centre of potential accessibility distribution

The spatial distribution of potential accessibility also determines the weighted mean centre, which gives interesting information about the location of the centroid point. In general, the weighted mean centre (geographic centre), is a two-dimensional average weighted by a variable and for accessibility it is calculated according to the following formula:

$$\bar{x} = \frac{\sum_{i=1}^n A_i^{(D)} x_i}{\sum_{i=1}^n A_i^{(D)}}; \bar{y} = \frac{\sum_{i=1}^n A_i^{(D)} y_i}{\sum_{i=1}^n A_i^{(D)}} \quad (3)$$

where \bar{x}, \bar{y} = centre (centroid); A_i = accessibility of transport zone i to destination attractiveness D ; x_i, y_i = coordinates of transport zone i ; n = number of transport zones (362).

For this calculation we used the mean centre tool in the QGIS Desktop 3.6.0 application with GRASS 7.6.0.

3. Study area

Krakow is the second largest city in Poland, the capital city of Malopolskie Voivodship, an academic and cultural centre, Poland's largest tourist destination (Więckowski

and Saarinen, 2019) and one of the richer Polish cities. The territorial development of Krakow occurred through the inclusion of neighbouring areas, particularly Nowa Huta, the easternmost district developed to provide housing for a large steel mill built from scratch in 1951. In 1973, the city limits were extended again and rural areas surrounding the city to the east, south and west were incorporated into it. Krakow is divided into 18 districts.

3.1 Some aspects of travel behaviour

For urbanised areas, commuting to schools is identified in a detailed and cyclical manner as part of comprehensive traffic surveys. Commuting to schools (by students) is one of the most important travel motivations in traffic research, usually in second or third place after commuting to work and possibly shopping. This proportion (of all trips) is usually about 12% of all travel (see Tab. 3). The share of public transport in travel related to education is quite variable depending on the city analysed, and in Poland it varies from 35% in Gdansk to as much as 51% in Kraków.

3.2 Land-use component

The number of inhabitants of Kraków has remained at a similar level (around 750,000 inhabitants) for a long time, but changes can be observed between districts. The number of residents registered for permanent residence in the inner-city districts has been decreasing for years: in the Old Town, Krowdrza and Nowa Huta there was a decrease of about 10–15% in the period 2009–2016. These districts are inhabited by an aging population, while young and middle-aged people prefer to live in more modern districts of the city. In Kraków many new housing estates are being built and the largest increase in the number of inhabitants has been seen in the southern (Dębniaki, Swoszowice and Podgórze) and northern areas (Prądnik Biały) of the city.

This work focuses on the distribution of public and non-public upper secondary, following the education system in Poland where upper secondary schools are divided into general upper secondary schools, technical secondary schools, basic vocational schools and other upper secondary schools. In recent years, the number of secondary schools in Kraków has remained at a similar level, with any changes mainly resulting from the reform of the Polish education system. On September 1, 2017, each existing six-year primary school covering grades I–VI became an eight-year primary school covering grades I–VIII, so lower secondary schools, ('gimnazja') ceased to exist, resulting in an increase in the need for places in upper secondary schools, where the number of educational years increased from three to four.

Travel purpose	Gdańsk 2016		Warsaw 2015		Poznań 2013		Krakow 2013	
	(to/from) school	(to/from) university	home-school	school-home	to school	to university	home-education	education-home
Share of education trips	14.40%	11.10%	6.40%	18.20%				
Walking	40.61%	12.53%	32.20%	35.30%	21.20%	5.30%	38.20%	39.30%
Car	13.38%	14.90%	16.00%	13.90%	23.10%	18.10%	8.80%	8.90%
Public transport	35.13%	67.17%	49.20%	48.00%	50.70%	72.40%	51.40%	50.80%
Bicycle	10.80%	5.40%	2.20%	2.60%	2.10%	3.80%	1.10%	0.70%
Other mode	0.08%	0.00%	0.40%	0.20%	3.00%	0.30%	0.50%	0.30%

Tab. 3: Share of travel related to education and mode in selected cities in Poland. Sources: authors' analysis based on KBRs (Kompleksowe Badania Ruchu [Comprehensive Travel Surveys]) from Gdańsk (KBR in Gdańsk, 2016), Warszawa (KBR in Warsaw, 2015), Poznań (KBR in Poznań, 2013), Kraków (KBR in Kraków, 2013)

For the purposes of this study, the number of pupils was aggregated into 362 transport zones. At the end of September 2016, 145 upper secondary schools were identified in Kraków according to data provided by the Board of Education in Kraków (SIO, 2016), with nearly 32 thousand pupils attending them. Young people usually choose general upper secondary schools – in 2016 almost 58% of students took lessons in this type of school. About one third of pupils were taught in technical secondary schools, and about 8% chose basic vocational schools. The upper secondary school system has a moderate degree of centralisation.

Therefore, pupils who do not live within the city are a minority. Data provided by the Central Statistical Office in Poland indicate that pupils of upper secondary schools commuting or temporarily living in Kraków (e.g. in boarding

schools) constitute approximately 10% of upper secondary school attendance (GUS, 2018). In order to simplify the analysis, such students were not taken into account in calculating accessibility levels.

One can observe an uneven spatial distribution of upper secondary schools within the boundaries of the City of Kraków. Most schools are located in the central part of the city and in Nowa Huta. It is clearly visible that the supply of schools is definitely larger on the northern side of the Vistula in comparison with the southern part of the city, where only a few facilities are located. Nevertheless, accessibility to secondary schools depends not only on their distribution, but also on the spatial relations between schools and their pupils' places of residence, as well as the state of the public transport system.

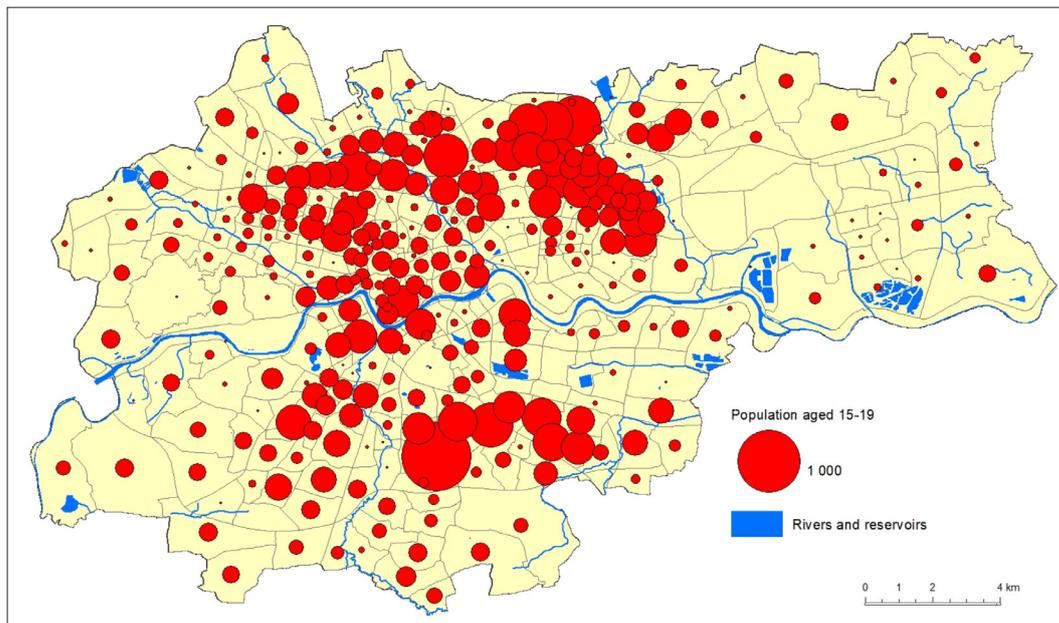


Fig. 1: The number of inhabitants aged 15–19 in 2015

Source: authors' analysis based on demographic data from Imagis. The division into 362 transport zones was based on the existing spatial structure of the city (Szarata, 2014)

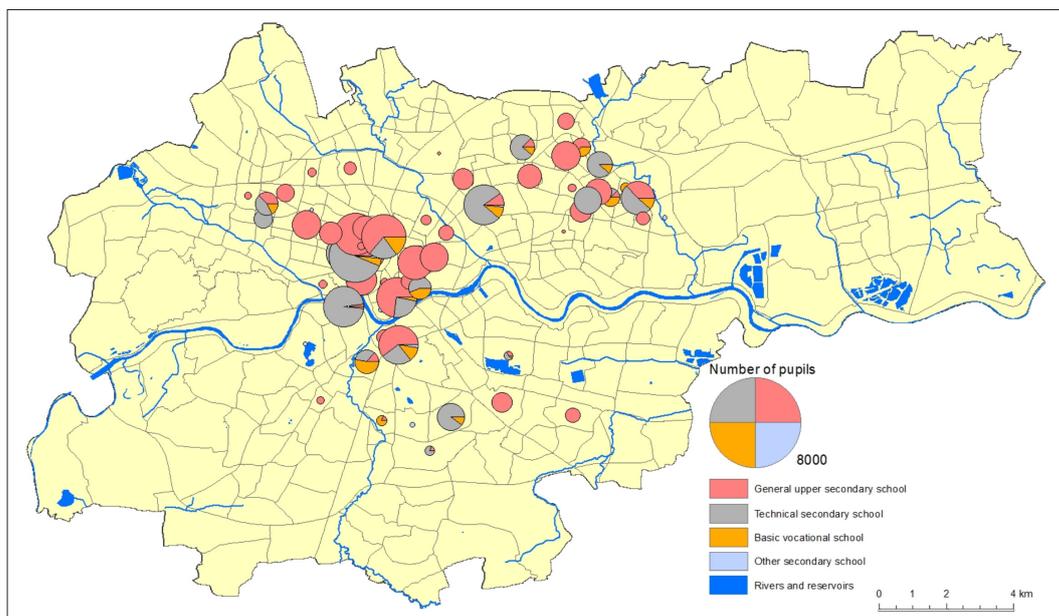


Fig. 2: Distribution of different types of upper secondary school in Kraków (number of pupils in 2016)

Source: authors' analysis based on SIO data as of September 30, 2016

3.3 Public transport system

In Kraków there are 27 tram lines and 161 bus lines (including 72 suburban lines: data for 2017). The total length of tram lines is 353 km and is entirely within the administrative borders of Kraków. The length of bus lines is 2,385 km, of which 1,601 km is within the Krakow City limits. Figure 3 shows the public transport system in Kraków with additional information about areas with access of less than 5 minutes on foot to the nearest bus or tram stop. The areas of high accessibility (5 minutes walking to the stop) are mainly areas with high density buildings. The additional analysis shows that 90% of young residents of Kraków (aged 15–19) have access to a bus stop within 5 minutes on foot.

4. Methods

The level of accessibility can fluctuate greatly throughout the day as a result of congestion or timetables, and a non-linear relationship exists between public transport frequency and losses of precision in measuring accessibility (Stępnia, Pritchard, Geurs and Goliszek, 2019). Therefore, to take into account the temporal dimension, in this paper we use the results of a comprehensive travel survey of Kraków (KBR in Kraków, 2013) in which three main purposes of travel were taken into account: commuting to work, travel to school and other travel. According to the results from KBR in Kraków (2013), 50% of all trips to schools start between 7:00 am and 8:00 am. For this reason, we focus on the morning rush hour and the chosen time at which one gets into public transport, which was used to calculate the level of accessibility, set at 7.00 am resulting in a matrix of travel times between 362 travel zones. For calculations, we use data in the General Transit Feed Specification (GTFS) (see Goliszek, 2021) standard on public transport timetables. We measure accessibility at the centroid of the transport zone. The pedestrian time both to reach the tram or bus stop and to access the internal travel time in formula [2], was determined on the basis of the assumed average speed of access which equals 4.82 km/h.

In order to estimate the distance decay function, we use a sample of 1,471 home-school-home trips carried out by

public transport within the boundaries of Kraków (KBR in Kraków, 2013). The process of estimating distance decay functions has been divided into two stages, using the methodology presented in Salze, Banos, Oppert, Charreire et al. (2011) and Skov-Petersen (2001): (1) matching the type of impedance function; (2) determining the parameters of the adopted function. At the stage of looking for functions, tests were made with non-linear and linear regression models that would best reflect the relationship identified (Tiran, Lakner and Drobne, 2019). In the process of searching for the shape and parameters of the distance decay function, a linear regression model was used, and for this purpose the Statgraphics tool was used. We assumed that the probability of the trip was the dependent variable, and the travel time in minutes was an independent variable. The following formula was determined to be the distance decay power-exponential function (see also Halas and Klapka, 2015):

$$F(t_{ij}) = \exp(-\beta t_{ij}^2) \quad (4)$$

where $F(t_{ij})$ = distance decay function; t_{ij} = travel time (min); β = beta coefficient; $\beta = 0.00122876$.

From the analysis of variance resulting from this analysis, a p-value of less than 0.05 was obtained, which means that there is a statistically significant relationship between the variables (share of travel and travel time) at a confidence level of 95%. A quality assessment of the model was made, resulting in a coefficient of determination $R^2 = 86.79\%$. The same *beta* parameter was used both for population potential, as well as for upper secondary school potential. Moreover, we also used the same distance decay function in calculating the so called self-potential. Following Rich (1978) and Gutiérrez, Condeço-Melhorado, López, Monzón (2011), we assume that when calculating the portion of potential generated internally, the surface of the transport zone is equated to a circle, the average travel distance is half the radius, $0.5\sqrt{\frac{area}{\pi}}$, and the assumed internal travel speed, \bar{v}_i , is 4.82 km/h, which takes into account the pedestrian speed due to the fact that the majority of pupils go to school on foot if located in their own transport zone.

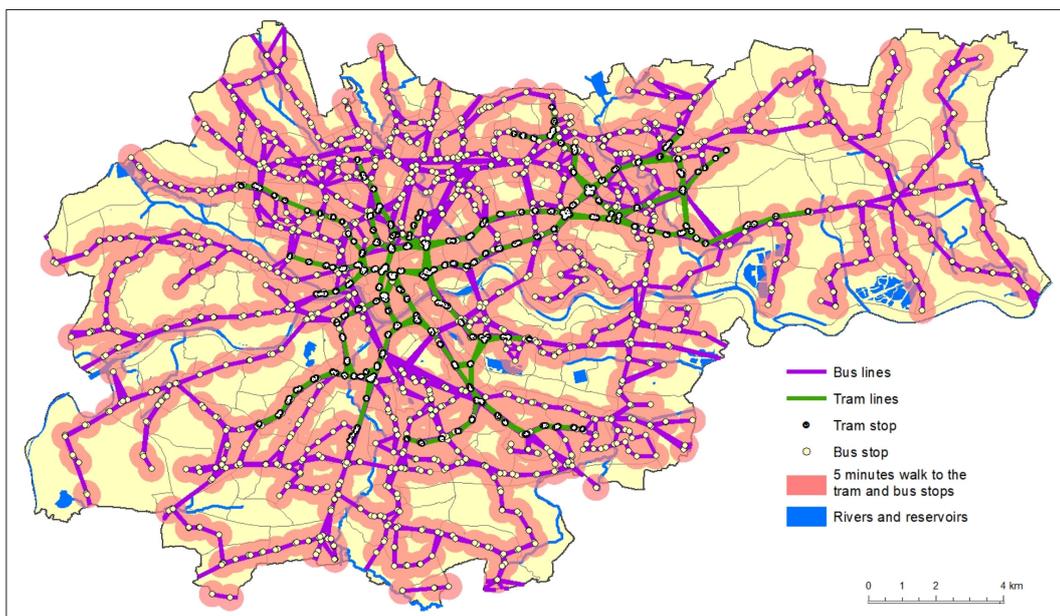


Fig. 3: Kraków public transport system – tram and bus stops within 5 minutes walking time
Source: authors' analysis

The analysis of the accessibility of upper secondary schools was conducted for each of the main types of schools independently (general upper secondary schools, technical secondary schools, basic vocational schools), as well as for all upper secondary schools together. In order to enable comparisons of the spatial differentiation of results, the total sum of results of potential accessibility indicators for the whole city was equated to 1 000 for each accessibility calculation.

A similar procedure was adopted for the potential quotient analysis. For the purposes of comparative analysis, we applied the simplified version of the potential ratio assuming that the total sum of values of both nominator (educational potential) and denominator (population potential) are identical. Then, the potential quotient was calculated for each region independently. The numerical values are multiplied by 100 in the graphics, which means that if the index is higher than 100, then the educational potential exceeds the population potential, and if the index is below 100, then the educational potential is lower.

5. Results

The results presented focus on the spatial aspects of the potential accessibility distribution, with particular attention given to the potential quotient, the mean centre of potential accessibility and potential accessibility dispersion index, concerning both the number of school-age pupils and upper secondary schools.

The spatial distribution of the population aged 15–19 and the pupils in upper secondary schools are generally similar to each other in Kraków. Therefore the potential accessibility pattern also looks similar both for accessibility to the population and accessibility to upper secondary schools. The most accessible areas for pupils are those located in the vicinity of schools, i.e. mainly in the city centre and north-east of the centre, as well as along tram lines and selected high-frequency bus lines.

Nowa Huta and its neighbouring districts, as the area of dominance of heavy industry including the steel industry, are characterised by a relatively higher density of technical

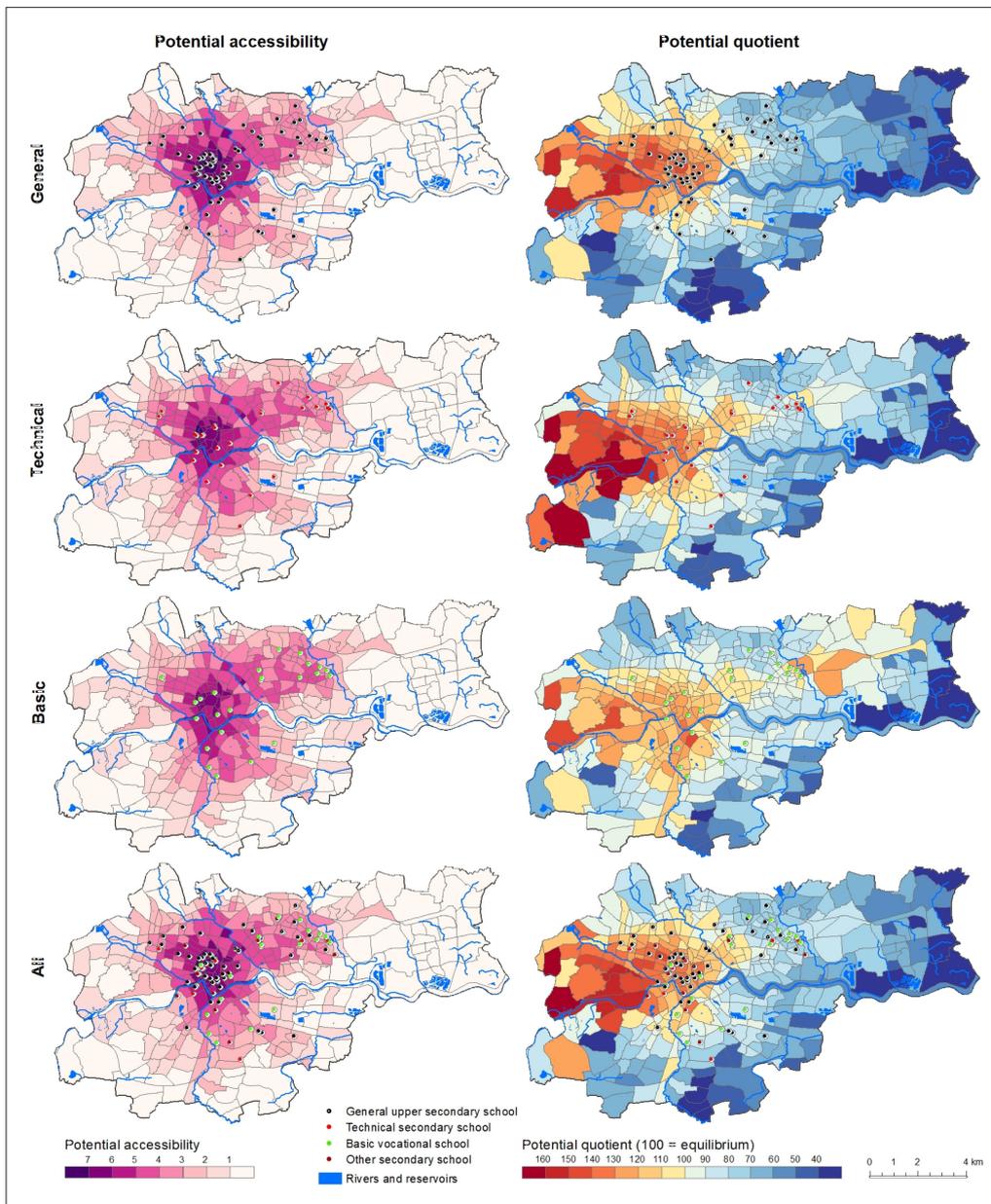


Fig. 4: Potential accessibility of different types of upper secondary school and potential quotient
Source: authors' analysis

secondary schools and, in particular, basic vocational schools. Therefore, pupils inhabiting these areas have relatively better access to the above-mentioned types of schools. The lowest level of accessibility within the boundaries of the city is found in the southern parts of Kraków and in the far eastern parts of Nowa Huta. In the case of Nowa Huta, the situation in this respect was improved by the modernisation of the tram line to Pleszów (Nowa Huta). Further improvement will be possible in the next decade if plans to build a new metro line in Krakow are implemented (east-west connections between Bronowice and Nowa Huta).

At first glance, due to the quite similar distribution pattern of population and education potential accessibility, the mean centres of both indicators are located close to each other (near the Mogilskie roundabout; see Fig. 5). Nevertheless, the results provided by the potential quotient analysis (Fig. 4), show that the surplus of upper secondary school potential over the people aged 14–19 potential is clearly visible in the western part of the city, primarily in the Zwierzyniec district. This result is confirmed by the fact that the weighted mean centre of the potential to upper secondary schools is located a little westward of the population mean. Despite the relatively large number of schools in the north-eastern districts, there are usually less pupils compared with the large upper secondary schools in the city centre. Moreover, the population is more proportionately distributed between these two clusters of upper secondary schools. Thus, the eastern districts can be considered as not sufficiently equipped with secondary schools. This is similar to the southern districts, i.e. Podgórze and Swoszowice, which are rapidly growing in terms of population, and which are also characterised by a surplus of population potential over upper secondary school potential.

In terms of infrastructure investments, especially new tram lines, the city of Krakow has met expectations by launching a new tram line to Płaszów in 2010 (there are advanced plans to extend it up to the S7 eastern ring-road). Because of this investment, young people living in this district have the opportunity to travel rapidly towards the city centre, where the secondary schools are located (Jurkowski and Smolarski, 2018). Currently, the city is also carrying out an investment consisting of the construction

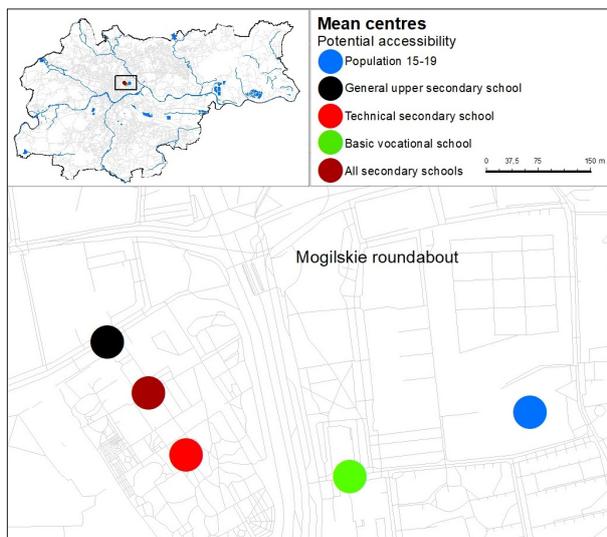


Fig. 5: Mean centres of potential accessibility of the number of school-age individuals and the different types of upper secondary schools
Source: authors' analysis

of a tram line along the Łagiewnicka Route (connecting the housing estates in Kurdwanów with the Zakopiańska route), which will result in the creation of a tram ring in the southern districts of the city. Nevertheless, the location of additional upper secondary schools in the above-mentioned areas will affect the provision of more equal access to education facilities for pupils living in Kraków.

The analysis of the Potential Accessibility Dispersion (PAD) index confirms the above-mentioned results. The spatial inequality is highest for general upper secondary schools (PAD index above 0.7), while technical secondary schools and basic vocational schools seem to be more equally distributed. Nevertheless, the values do not differ a lot when compared with the PAD index for the population aged 15–19, which is an acceptable result from an educational policy point of view (see Tab. 4).

Index	Population aged 15–19	Upper secondary schools			
		General	Technical	Basic	All
PAD index	0.580	0.702	0.659	0.640	0.680

Tab. 4: Potential accessibility dispersion (PAD) index
Source: authors' analysis

6. Conclusions

After commuting to work, commuting to schools is the second most important travel motivation for public transport users within the city. Taking that into account, the relatively small number of studies of the accessibility of schools, in particular those at the medium level of centralisation, i.e. upper secondary schools, is quite surprising.

We conclude that local differences in the level of potential accessibility and potential quotient in the context of secondary schools should become an important premise for making decisions regarding new locations of school facilities. This is particularly important in Poland, and more broadly also in selected countries of Central and Eastern Europe, including the Czech Republic and Slovakia, where in the years to come there will be a slight increase in the group of pupils aged 15–19.

Those cities in which selected peripheral districts had an industrial function in previous decades (as in Nowa Huta in Kraków) may suffer from an unbalanced spatial distribution of different types of schools. Therefore, it is recommended that in the future new schools should not only be located in the context of a new residential area, but also to better balance access to different types of schools throughout the city. It is in this context, that the new location of a general upper secondary school might be considered in the southern or eastern part of Kraków. Nevertheless, the picture of inequality would be a little different if the study also included the suburban zones. Similar research in the future should also take into account the population living in the entire agglomeration outside the city core and the timetables of suburban trains and buses used by pupils in their daily commuting to schools.

Moreover, it is important to consider public transport schedules adapted to the needs of commuting to/from schools in order to increase the level of accessibility (Guzik, 2003a). A fairly large variability in the level of potential quotient

between neighbouring peripheral transport regions was observed in the morning rush hour. Thus, it is important to develop a comprehensive policy that takes into account both the spatial and temporal components of the accessibility of upper secondary schools.

Moreover, there is a need for greater emphasis on the study of the relationships between spatial policy, housing policy and transport policy, both at the city level and in its surroundings. The use of potential accessibility indicators, including also demand and supply conditions, is among the ways to speed up the planning process in the case of the provision of additional secondary schools. The potential quotient method presented can be used for accessibility monitoring and planning. By changing the number of places in schools and using forecasts of the number of lower secondary school graduates, it is possible to simulate changes in accessibility. Interpretation of the results in terms of supply and demand makes it possible to apply this methodology to studies of accessibility to other services, both on a regional, local and intra-city scale (Guzik, 2003b). The proposed method can be used to analyse differences in accessibility to various types of services, not only educational services, but also, for example, to shops, hospitals etc.

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