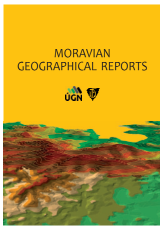

MORAVIAN GEOGRAPHICAL REPORTS

sciendo

The Czech Academy of Sciences, Institute of Geonics
Palacký University Olomouc, Faculty of Science

journal homepage: www.geonika.cz/mgr.html

doi: https://doi.org/10.2478/mgr-2023-0002

Changeability of transport behaviour in a large city from the perspective of working days and Sundays: The case of Łódź, Poland

Szymon WIŚNIEWSKI [a] *, Marta BOROWSKA-STEFAŃSKA [b], Maxim DULEBENETS [c], Michał KOWALSKI [a], Edyta MASIEREK [b]

Abstract

The transport behaviour of Lodz residents with a view to constructing a balanced traffic model to include both private and public transport is examined in this paper. A survey was conducted among 6,000 Łódź citizens using mixed-mode techniques: CAWI and CATI: respondents were asked to complete a travel log for the previous day and the previous Sunday. This served as a basis for further analyses, performed with PTV simulation software, following a four-step model. The main results of the study are presented, including the mobility rate of Łódź residents, the motivations and duration of journeys, and the division of transport tasks into workdays and Sundays, indicating that a higher private carload is typical for home-other and other-home trips on Sundays compared to working days. The number of home to work and work-home trips via private cars is higher for working days compared to Sundays. Furthermore, the simulated traffic load of the public transport system is much higher for working days compared to Sundays. A higher percentage of non-motorised trips and longer trip duration are found to be common for Sundays as well.

Keywords: *transport behaviour, macroscale traffic model, survey research, Łódź, Poland*

Article history: *Received 21 June 2022, Accepted 16 February 2023, Published 31 March 2023*

1. Introduction

Numerous modern cities face challenges from the negative effects of human activity, including those directly related to traffic, mostly private cars. Not only does road transport generate noise and pollute the air, but it also results in congestion, parking issues, and accidents (Proost & Van Dender, 2001). Before the 1990s, successive infrastructural investments were introduced to reduce the negative effects of traffic, especially congestion. These proved to be not very effective, however, and, as a result, they have been superseded by traffic forecasting (Wismans et al., 2014). Traffic models constitute a mathematical representation of the structure of transport demand based on research into travel behaviour within a given territorial unit. Traffic model tools are currently applied in, among others, transport studies for the diagnosis of transport system performance, traffic forecasts for specified strategic initiatives, and transport-related studies for investment projects (Boarnet & Sarmiento, 1998; Barceló, 2010). The actual description of a transport system is quite challenging, due to the high complexity of transport subsystems and correlations between their individual components (e.g. time). This is where traffic models come into play, with mathematical models providing a sufficiently accurate representation of a given transport system (Fielbaum et. al., 2017).

The development of traffic models is enhanced by the collection of relevant data that describe transport needs, journeys taken, and the operations of the transport system itself (Meyer, 2016). The volume and detail of these data are determined by the structure of the traffic model for a given area and the scope of the project it is intended to serve. Surveys on residents' mobility within a given province, metropolitan area or city are key elements in the process of building traffic models (Karoń & Mikulski, 2013).

The significance of these results for the development of the social sciences, social and economic geography, as well as spatial development, is difficult to be overstated. The accomplishment of this research project fills a gap concerning the characteristics of

[a] Institute of the Built Environment and Spatial Policy and Research Center for European Spatial Policy and Local Development, Faculty of Geographical Sciences, University of Łódź, Poland (*corresponding author: S. Wisniewski; e-mail: *szymon.wisniewski@geo.uni.lodz.pl*)

[b] Institute of the Built Environment and Spatial Policy, Faculty of Geographical Sciences, University of Łódź, Poland

[c] Department of Civil & Environmental Engineering, Florida Agricultural and Mechanical University (FAMU) and College of Engineering, Florida State University (FSU), USA

transport behaviours of Łódź inhabitants. The analyses carried out using the questionnaire survey were a necessary supplement to the set of quantitative data collected so far in the literature (including the spatial and temporal structure of vehicle traffic), concerning the functioning of the Łódź transport system. They made it possible to learn the travel motivations undertaken by people in spatial terms and at a certain time, using the modes of transport chosen by them. The conducted survey studies belong to the only reliable sources of knowledge that comprehensively provide knowledge about the demand for transport services. Nowadays, conducting extensive social research is considered one of the basic elements of creating transport policy. The obtained data can be used in prognostic analyses of the development of the transport system in order to meet, for example, the requirements related to sustainable urban transport.

This paper analyses the transport behaviour of residents in the City of Łódź (Poland), with a view to building a balanced traffic model for private and public transport. To conduct a detailed analysis of transport behaviour, the study included travel logs (one for a weekday, and one for a Sunday) to provide an insight into the routines of journey-takers and to indicate their main destinations (Stopher, 1992; Axhausen et. al., 2002). As there has yet to be a traffic model for Łódź, this study may be considered quite innovative. According to the 2020 TomTom Traffic Index, Łódź was the most congested Polish city (Rogulski & Badyda, 2021), thus, the construction of a mathematical model for the city is seen as vital for both traffic management and the planning of new investments. Since congestion of the transport system translates into the irregular operations of the public transport system (which is taken into account by the residents), it is imperative to introduce and then systematically monitor and revise strategies and practices to reduce the demand for car travel. The decision-making process when selecting a given mode of transport is based on many variables, hence, it is vital to create traffic models that considers people's mobility needs and behaviour (mobility management). Importantly, however, each city possesses unique conditions that impact the trips within its boundaries. For this reason, a traffic model requires an individual approach for each given city.

2. Theoretical background

Transport behaviour is defined as the actions (variously motivated) taken in a specific space and time to travel using a particular mode of transport, and is determined by social, economic, spatial and organisational factors. Research on transport behaviour in developed countries began in the mid-twentieth century. Liepmann (1945) explored the correlation between travel time and cost, and modal selection through the analyses of commuter data, while the very first researchers to investigate the relationship between land use and transport behaviour were Mitchell and Rapkin (1954). Concepts of transport behaviour evolved to include analyses of mode choice (Ben-Akiva & Lerman, 1985; Sayed & Razavi, 2000) and the impact of land use and urban design on transport behaviour (Handy, 1996; Kockelman, 1997; Boarnet & Crane, 2001). The development of theories on transport behaviour has led to the emergence of mathematical models for the selection of the mode of transport based on the economic measurement of satisfaction, i.e. maximisation of satisfaction resulting from its usability. These models have formed the basis of studies by a number of researchers, including Boarnet and Crane (2001). They are based on the idea that the choice of where one resides depends on the location of the workplace and the other potential destinations that satisfy our needs. This in turn impacts our transport behaviour.

The transport behaviours of city residents and the factors that affect them have long been the subject of scientific research (e.g. Bruns & Matthees, 2019; De Vos et. al., 2018; Cao & Ermagun, 2017; Stevens, 2017) and field studies (e.g. Transport Behaviour among Residents of Large Cities, 2021). The findings of such studies enhance mobility management, urban planning and infrastructure development, both technical and public. The dominant types of research are empirical studies that link travel decisions (e.g. choice of transport mode) to land-use, transport infrastructure, socio-demographic and personal traits and preferences. Theoretical work is also emerging where authors attempt to formulate universal models that encompass the above (e.g. Van Acker et al., 2010).

In Poland, an increased interest in this issue came relatively late. It is only in the last two decades that publications and studies on the subject began to emerge, though still relatively few when compared to other urban issues researched. It is, therefore, reasonable to conduct analyses on various dimensions of transport behaviour among city dwellers in Poland to enrich the global scientific output with the local perspective and to contribute to the international discussion on this topic.

Expanding knowledge on the preferences of road users is a prerequisite in the process of shaping their transport behaviour, the main aim of which is to provide a fast, safe, efficient, and environmentally friendly transport system that addresses the needs of the various social groups. As shown by numerous studies, people's transport behaviour is largely determined by the place of residence (e.g. van de Coevering et. al., 2018; Wang & Lin, 2017; De Vos & Witlox, 2016; Ewing & Cervero, 2010; Cao et. al., 2009). Residents of areas close to the city centre – densely built-up districts with diverse facilities and a well-developed public transport system – are more likely to eschew owning a car, being instead more willing to walk, cycle or use public transport (De Vos et. al., 2018; De Vos & Witlox, 2013; Ewing & Cervero, 2010). In turn, residents of sparsely populated areas with low-density housing and poorer access to public transport and necessary amenities, are less likely to use public transport and therefore have to rely on the car.

A key factor affecting the mobility decisions of residents is the nature of the local transport system. The level of accessibility and the quality of the transport infrastructure dictate choices in terms of modes of transport, number of daily trips and directions of travel. Residents of residential areas located in close proximity to public transport tend to use public transport services far more frequently than residents of areas more distant from such infrastructures (Lane, 2008; Hass-Klau & Crampton, 2002; Gadziński & Radzimski, 2015).

The authors suggest that understanding of the factors that affect transport behaviour is an important element when developing and improving public transport services. Before deciding whether to opt for public transport, people consider whether the vehicles run on schedule, if they can travel without having to change, if they feel safe on the vehicles and at the stops, and how easily accessible the stops are. The authors also feel, however, that determinants of a psychosocial nature are equally important, including personal routines, preferences and currently-promoted pro-environmental attitudes.

Demographic changes and socio-economic development have impacted residents' transport behaviour to the detriment of their environment. The ever-increasing number of cars results in higher exhaust and noise emissions, traffic congestion, and reduced road safety. This poses a challenge to authorities, who must continuously attempt to improve the efficiency of the city's transport system (Wójcik, 2020). Any research effort which addresses this issue and provides guidelines for the necessary changes in cities therefore will be not only a contribution to the theoretical development of the field, but may also facilitate the process of changing transport systems in cities for the better.

Residents of large cities usually display greater mobility than those living in small towns and villages, mainly due to the increased density of travel destinations, their location, and the distance between them. This is why a considerably larger number of analytical studies focus on the residents of large cities, including this article. The results on mobility in Lodz enable comparative analyses with other urban centres, and complement research projects that have already been undertaken in this area.

3. Area under study

Łódź is a large city, whose population – according to the 2020 data provided by the Central Statistical Office – amounted to 672,185 residents, including 55.73% people of working age, 29% of post-working age and 15.27% of pre-working age. The highest population density is recorded in the city centre (defined as the area within the boundaries of the ring railway) (Fig. 1).

The spatial mobility of the population is impacted, *inter alia*, by the land use within the boundaries of a given area, which makes the analysis of the transport system (Fig. 1), land use, including the location of recreational facilities, parks, and public buildings (Fig. 2), particularly important. International, national and regional roads, as well as the ring railway line run within the city limits. Due to its specific (ring-shaped) course, however, the latter remains outside of the major factors that shape the public transport in the city.

In Łódź, the overall travel volume is dominated by non-pedestrian trips (87.67%), particularly by private cars (both on working days and Sundays). This can be partly attributed to the city being at the centre of its region, and far from other large urban centres. As a result, Łódź residents display high mobility – mainly for work purposes. Importantly, the standards of the services provided by the city's public transport system fail to meet the expectations of the general public (Borowska-Stefańska et al., 2020).

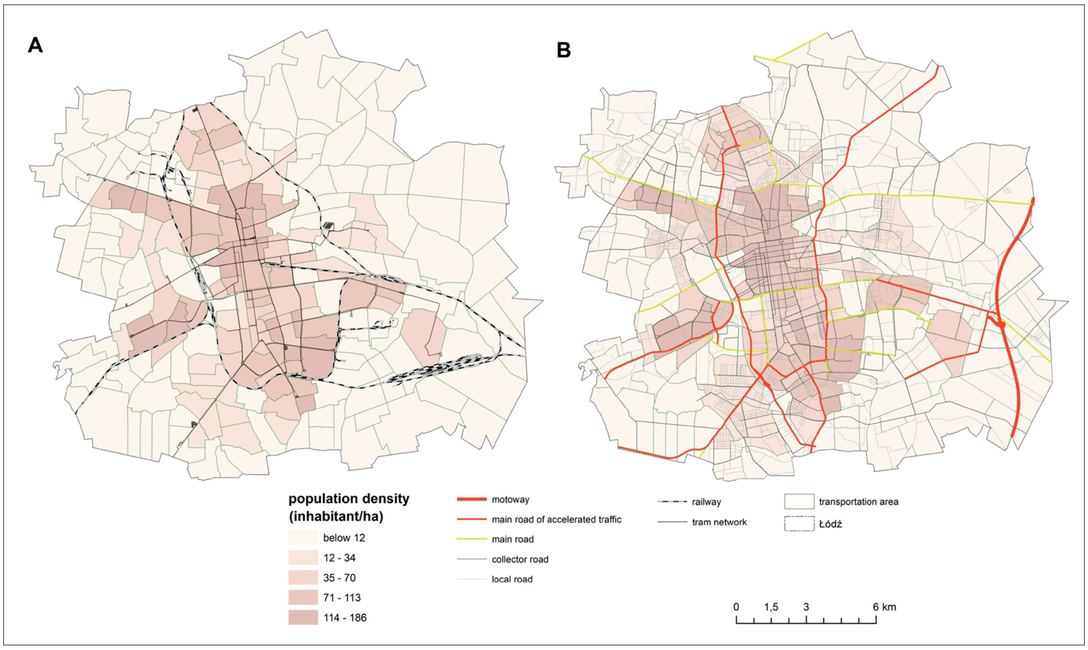

Fig. 1: Railway (A) and road (B) infrastructure and population density in Łódź
Source: authors' elaboration based on data from City Hall

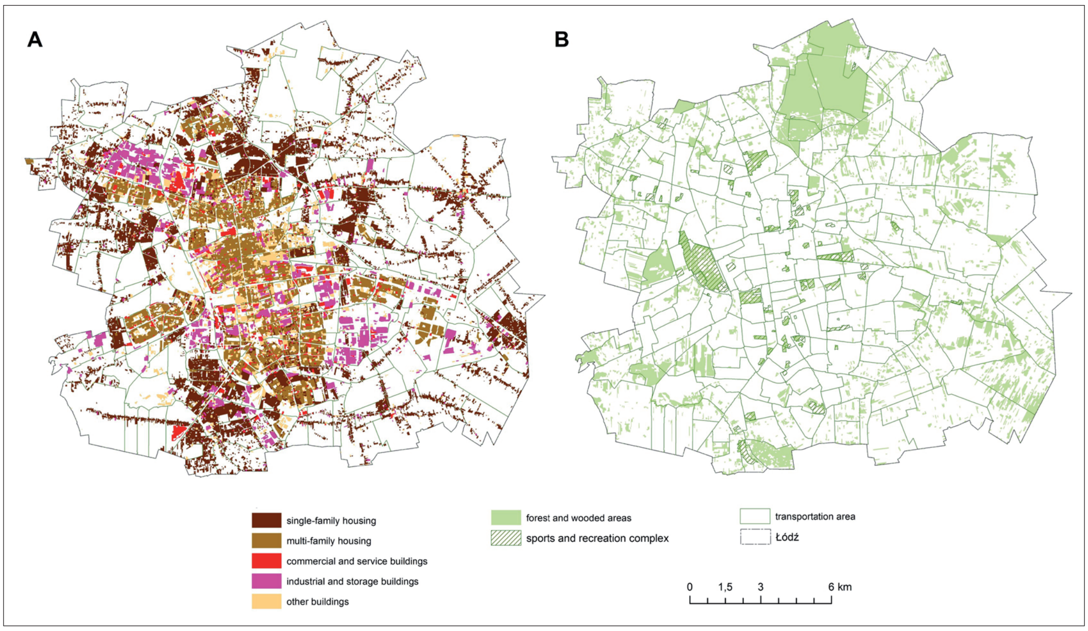

Fig. 2: Distribution of housing (A), green areas and recreational facilities, including sports (B) in Łódź
Source: authors' elaboration based on data from Database of Topographic Objects.

The spatial distribution of residential and industrial areas as well as retail and service-related facilities is an important factor when transport needs are analysed. In areas that are dense and mixed-use, the resulting short distances between the places of residence, work, education and leisure favour the bicycle as a commonly chosen means of transport (Rixey, 2013). In Łódź, however, the dominant type of land use is residential (single- and multi-family housing), with industrial facilities being primarily located outside the city centre (in the north-west and south), whereas retail and service-related facilities are predominantly located in the city centre (Fig. 2).

4. Research methods

The entire research procedure is captured in the following Flow Chart (Fig. 3).

4.1 Questionnaire survey

To analyse the transport behaviour of Łódź residents – without which data a traffic model for the city could not be developed – the authors conducted a survey using a mixed-mode technique that combined CAWI (Computer Assisted Web Interviewing) and CATI (Computer Assisted Telephone Interviewing). The development of a model is impossible without access to a variety of data, including that on transport needs, trips taken, and the operation of the transport system itself (Meyer, 2016). The questionnaire was meticulously designed and pre-tested through a pilot study conducted among Łódź residents in the autumn of 2018.

The actual survey involved 6,118 residents of Łódź, aged 13+ (4,220 respondents interviewed with the CATI technique; 1,898 secondary school students with the CAWI technique). The sample was representative with respect to the city's population aged 13+ and place of residence (covering the various districts of Łódź) and included slightly more than the 1% of the city's total population within the age bracket – that is the sample size (the number of questionnaires completed) that should be the minimum for large Polish cities. This corresponds to the recommendations for survey coverage in studies conducted on cities with similar demographic potential found in other parts of the world (Button & Hensher, 2005; Horbachov et al., 2022). The surveys were conducted during selected weeks in October, November and early December 2021, from Tuesday to Saturday, but asked about the last workday and last Sunday. These periods were chosen as they were devoid of any anomalies that could impact the analysed behaviour while retaining all travel motivations and the typical frequency of trips related to them. As the research was conducted during the pandemic, however, the technique of Computer-Assisted Personal Interviews (CAPI) had to be abandoned to reach the highest possible number of respondents.

The actual survey questionnaire consisted of three parts: (1) the respondent's socio-demographic characteristics; (2) questions on consumer behaviour, both prior to 2017 and today; and (3) a travel log. This paper discusses the data from two of these sections, the first and the last. The opening section contained the details of the respondent and their household. The interviewees were asked about, or filled in, data regarding: gender, age, address of residence (postal code or street), type of housing, education, driving licence, primary occupation, and economic sector of employment. The next part concerned the whole household and data on the number of household residents, the number of children under 6, monthly net income per capita, and the number of bicycles, motorcycles, mopeds, and cars, if any. The analytical results of shopping-related transport behaviour compiled on the basis of the respondents' answers to questions in section 2, are presented, *inter alia*, in Borowska-Stefańska et al., 2022a and Borowska-Stefańska et al., 2022b.

The final section consisted of two travel logs, where the respondent was asked about trips taken during the preceding Sunday and the weekday prior to answering the survey. If no trips were taken on these days, they were to specify the reason behind it. Those respondents who travelled on the chosen days provided the number of trips, their origins and destinations, and the transport mode used. If these included public transport, they were also requested to specify whether there was a need to change the form of transport or transfer to another route but on the same form of transport within the city limits (and if so, how many times), and how long it took them to reach the first transport mode during a given trip. In addition, the travel log also requested that the respondents indicate whether they travelled alone and whether there were children under 6 among the passengers.

The research presented herein focuses on the period of the global COVID-19, which obviously had a significant impact on daily activities, including transport behaviour. The results

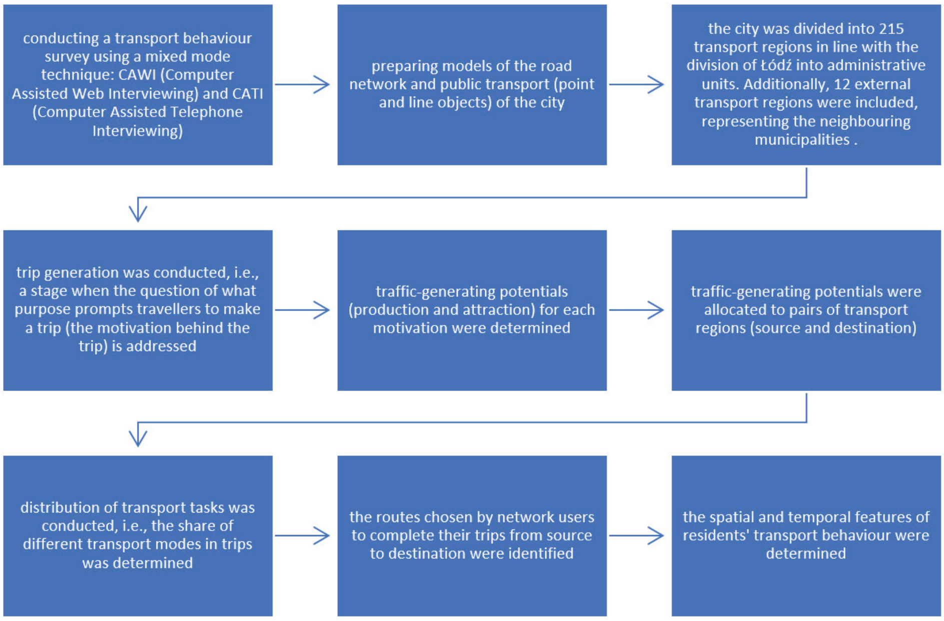

Fig. 3: A simplified plan of the research procedure
Source: authors' elaboration

presented in this paper can constitute a valid point of reference for analyses conducted at that particular time, capturing the actual changes in this matter. The existing studies clearly show that there was a significantly lower propensity to travel during the pandemic, which relates to public transport in particular (Bartuska et. al., 2022; Shibayama et. al, 2021). Previous studies of the transport system in Łódź covering the pandemic period clearly indicate a definite reduction in the spatial mobility of the city's inhabitants in the early days of the pandemic (spring 2020). This mainly stemmed from the mobility restrictions introduced in March 2020 and residents' fear of the new disease. Following an initial, dramatic drop in mobility, the situation changed towards increasing volumes later observed in both public and individual transport. Subsequent pandemic-related legal restrictions on mobility had a lesser impact on the observed traffic in the city, which stabilised in late 2020, albeit at lower levels than in 2019 (Borowska-Stefańska et al., 2022a). This study was conducted over six months after the period of observations cited above, at a time when the pandemic restrictions were becoming less severe and had an increasingly lower impact on residents' mobility (the restrictions in force at the time the questionnaire study was conducted, involved wearing masks indoors and limited access to certain services).

4.2 The local traffic model

Once the road network with public transport models (point and linear objects) of the city had been prepared (along with the parameters required for the subsequent traffic distribution), it was possible to conduct the following stages in line with the four-step approach (implemented entirely using the PTV Visum software). Step one was trip generation, i.e. the stage when it is necessary to determine what purpose motivates the road network users to make a trip. The study incorporated all motivations for using the urban transport system (and listed in the travel log), which were then aggregated to the following types of trips: home-work, work-home, home-education, education-home, home-other, other-home, or unrelated to home. Thus, it was necessary to determine the traffic generating potentials (generation and attraction) for each trip. The most applied trip generation model is the linear regression model, also referred to as a multiple regression model (Cordera et al., 2017; Schneider et al., 2015). For traffic generation, the model usually contains the demographic and socio-economic profile of the population within a given transport region, while for attraction, it is the properties of land use and development. With regards to the motivation behind commuting to work, it could be the number of the employees and jobs, or the number of business entities.

The second step is the spatial distribution of trips, which is simply the distribution of traffic generating potentials between pairs of transport origins and destinations. The result is an origin-destination matrix (O-D matrix), with a size corresponding to the number of transport regions graphically represented on a map of the transport system.

The third step involves a modal split which determines the percentage of the trips. There is a primary split, performed during the generation of trips, and a secondary split, following the spatial distribution of trips and resulting from a number of factors (distance, travel time, etc.) that are considered by the journey-taker. The selection of the transport mode is a complex process, conditioned by such factors as access to a private car or public transport, household income, perception of the comfort and convenience of the options available, trip motivation, and individual preferences regarding mobility behaviour. Once identified, it provides a basis for defining the dimensions of transport networks (density and capacity of the street network, density and capability of the public transport network, etc.), and for options that would alter mobility behaviour, e.g. measures taken to lower the percentage of private car journeys (Sawicki et al., 2016; Fierek & Zak, 2012; Bovy & Stern, 2012). The modal split applied in this study took into account both pedestrian and non-pedestrian trips. The former include trips made by non-motorised means of transport, e.g. bicycles and scooters, while for non-pedestrian travel, private cars and public transport (buses, trams, and trains) were modelled.

The final step is the distribution of traffic (user equilibrium) over the network. This is when the route taken by the users of the road network to travel from a given origin to destination is determined. The number of vehicles (and passengers) utilising a given section of the transport network (road, street, public transport line, etc.) is specified. Decisions may then be made on the type of intersection or hub, the dimension of road structures, how to plan traffic management, assess traffic conditions, and even strategically plan for situations that may occur in the future.

Regarding the data sources applied to build the supply model, the authors utilised the network data provided by geodetic and cartographic documentation centres, OpenStreetMap resources, and data retrieved from local authorities (the local public transport authority). To model the road network, road classes (motorway, fast traffic trunk road, main road, service road, local road, access road, other road) were assigned, with an additional division into grade-separated road segments, sections of increased or decreased capacity, and sections where traffic-calming measures have been installed. The course of tram and rail tracks was also taken into account. With respect to public transport, all bus, tram, and railway (the Łódź agglomeration railway) lines operating in Łódź were also taken into consideration, including night and replacement service. Depending on the period modelled, only those lines that were operational at a given time are represented in the simulations. All fixed components of the local public transport infrastructure (stops, terminuses, and stations) were also incorporated. Their distribution over the local public transport network required the network of stops to be recreated as a system of nodes. This was conducted in line with the following algorithm. First, the stops in Łódź were clustered using the criterion of spatial proximity, e.g. clusters may consist of stops on opposite sides of the street where a passenger can start a journey in two directions, or stops located at a particular junction where a journey is usually possible in more than two directions. When a given stop was not in close proximity to others, it was considered a single-spot cluster. Next, each stop from a given cluster received a cluster identification number. Then, based on the geographical coordinates of the stops within a given cluster, points with coordinates constituting their arithmetic mean were generated. These points were given both a cluster identification number and an ID for each stop within the cluster. As a result, a system of points and nodes was obtained that constituted a true representation of the fixed components of the transport network, and, at the same time, a simplification of its visualisation and the accommodation of further analyses, which included the construction of a graph.

The city was divided into 215 transport regions that corresponded to the official division into administrative districts. Additionally, 12 external transport regions were included, representing the municipalities neighbouring Łódź. External users were never excluded from the traffic model. Both employees commuting to and from Łódź were taken into account (based on the matrix data from the Central Statistical Office) while other travel motivations from neighbouring municipalities were also modelled. Moreover, transit traffic through Łódź, e.g. via the section of the A1 motorway (running along the eastern outskirts of the city) was also taken into account. The inclusion of outward source, inward source and transit journeys made the modelling process considerably more realistic. Demographic and socio-economic data was retrieved from public statistical data (e.g. the Central Statistical Office) and from the city authorities, pursuant to cooperative research agreements. The features of transport behaviour displayed by Łódź residents that are necessary for the construction of a macro-simulation model and its subsequent calibration were acquired through the questionnaire survey, as described in section 4.1. The authors also applied the results of traffic measurements taken automatically by the city's intelligent transport system (induction loops and ANPR cameras). With regard to the modelling of trip generation (demand model), the following attributes of the traffic regions were taken into consideration: total population, populations of working and school age, the number and capacity of schools, commercial and industrial facilities, and grocery and non-grocery shops. Generation of external traffic was additionally expanded with the matrix data on commuting provided by the Central Statistical Office, while data on traffic flows within the urban section of the A1 motorway was retrieved from the records in the 2020/2021 General Traffic Measurement by the General Directorate for National Roads and Motorways.

5. Results and discussion

5.1 The number and motivations behind trips, and reasons for not travelling

The study showed that mobility (defined as the average number of trips by a resident of Łódź per day) was low, amounting to 1.37 on weekdays and 0.82 on Sundays. The average mobility in Łódź was considerably lower than in the Krakow metropolitan area (2.02 trips on average made by Krakow residents, and 1.66 trips made by residents of neighbouring municipalities) (Szarata, 2015), Warsaw (1.99 trips per day) (Jacyna et al., 2016), the Poznan agglomeration (1.83 trips a day), and in the city of Poznan itself (Gadziński, 2016), the Pomeranian Province excluding the Tri-City (1.9 trips a day) (Jamroz et. al., 2014), Wroclaw (1.7 trips per day), and Gdansk (2.1 trips per day) (Gadziński & Goras, 2019). The observations recorded in Łódź were also noticeably lower than in previous years: 1.91 trips per day in 1974 (Gadziński & Goras, 2019), 2.13 trips in 1995 (Wójcik, 2020), 2.4 trips in 2013 (City Office, 2013), and 2.2 trips in 2014 (City Office, 2014). In all likelihood, the overall low mobility may have been due to the COVID-19 pandemic and the resultant changes in mobility among the population (increase in remote working, etc.) (Engle et al., 2020; Martin & Bergmann, 2021; Schlosser et al., 2020; Tarkowski et al., 2020). As shown by Borowska-Stefańska et al. (2022a), even though the effect of reduced mobility in Łódź was most conspicuous in the initial phase of the pandemic, a decrease in the load on the road network was also observed in its final period (when the questionnaire survey was conducted). In addition to the pandemic, the reduced mobility of Łódź residents on Sundays was also impacted by Sunday retail restrictions, the mobility-reducing effects of which are observable in the various transport subsystems in Łódź (Borowska-Stefańska et al., 2022a, Borowska-Stefańska et al., 2022b).

Economic accessibility to means of transport among Łódź residents remains at a threshold at which people would refrain from travelling due to lack of funds. The majority of respondents, however, explained that any decision not to travel was due to either no necessity, health issues, or legal restrictions related to the quarantine. A relatively large percentage of Łódź residents did not travel to work since they could perform their duties at home. As for Sundays, unfavourable weather conditions and guests at home were frequently indicated by Łódź citizens as the reasons behind their decision not to travel (Fig. 4).

Travel motivations of Łódź residents vary depending on the day of the week when trips were made. On weekdays, necessary trips dominate (slightly over 50% of all trips motivated by commuting to school or work), which is in line with other Polish cities (Szarata, 2015). By contrast, the percentage of necessary trips on Sundays drops to no more than 10%. On weekdays, optional trips are made mainly to shopping centres (15.4%), other shopping locations (6.3%) or commercial facilities (4.5%), followed by trips related to socialising (5.3%) and recreation (4.1%). The large percentages of shopping trips and visits to shopping centres are consistent with global findings (Zhang et al., 2021). In the UK, approximately 20% of all trips originating from home are related to shopping motivations (Guy, 2009), whereas in Poland, 10.2% of all trips are shopping-related (9.6% of all weekday trips and 14.2% of weekend trips), while in the Łódź Province this percentage amounts to 9.5% (9% on weekdays and 12.7% at weekends), and in the city of Łódź alone, to 8.2% (annually 37 trips per capita) (Central Statistical Office, 2015). Sunday retail restrictions, which affect shopping centres, are reflected in the increased percentage of trips made to visit these facilities on weekdays, with an increase in the share of shopping trips to locations other than the centres being observed on Sundays. More than one in four Sunday trips in Łódź is for social purposes, almost one in five for recreational activities, while almost one in ten is for religious needs (Tab. 1). When juxtaposed against the national average, the latter is relatively low, which is confirmed in the statistics published by the Institute of Catholic Church Statistics (ISKK, 2021) for the Łódź Archdiocese on the exceptionally low percentage of dominicantes in the parishes around Łódź.

The average multi-stage journey in Łódź consists of two trips, irrespective of whether it involves walking or another transport mode. For workdays, however, there is a noticeable increase in the percentage of journeys consisting of more than two stages (Fig. 5). The highest car traffic, regardless of the trip motivation, is recorded on the road network within the city's inner ring road network of streets and roads (an elliptical system with the meridionally elongated ellipse axis formed by national roads No. 91, 14, and 72), the main east-west road axis, and the arteries connecting the aforementioned ring road to distally-located neighbourhoods: the residential districts of Retkinia, Teofilow and Widzew, etc. (see Figs. 6 and 7). It was found that a higher private car load was typical for home-other and other-home trips

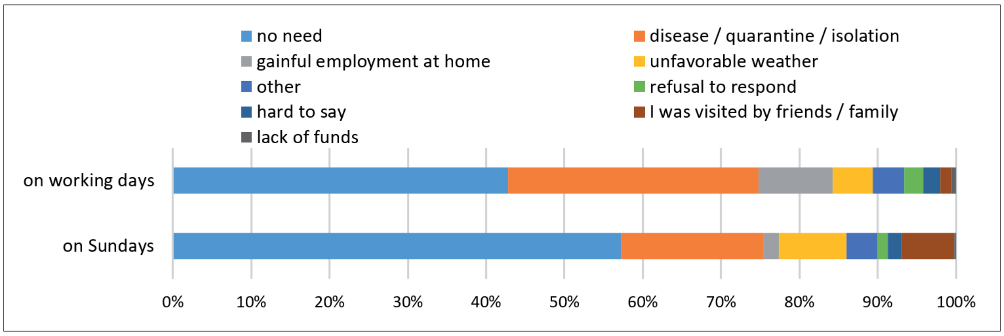

Fig. 4: Reasons for not travelling on weekdays and Sundays in Łódź in 2021
Source: authors' survey

Travel motivations	Working days (%)	Sundays (%)
Purpose related to paid work outside the home	42.4	8.9
Purpose related to shopping in a shopping and service centre	15.4	5.0
School or education purpose	8.4	0.2
Driving, escorting other people	6.6	1.9
Using the service sector (e.g. hairdresser, doctor, bank)	6.3	0.9
Social purpose (visiting friends or family in their home)	5.3	28.4
Purpose related to purchases at facilities not covered by trade restrictions	4.5	8.1
Purpose related to recreation / hobby / sport	4.1	18.6
Household matters	1.5	1.2
Entertainment and cultural purpose	0.9	5.2
Visit to a gastronomic establishment	0.8	4.2
Purpose related to religion	0.6	9.9
Motivation related to learning at the level of higher education	0.4	0.3
Purpose related to paid work at home	0.4	0.2
Tourism-related purpose	0.2	2.1
Other	1.6	3.6
Hard to say/don't remember	0.4	0.9
Refusal to respond	0.3	0.2

Tab. 1: Travel motivations on weekdays and Sundays in Łódź in 2021
Source: authors' survey

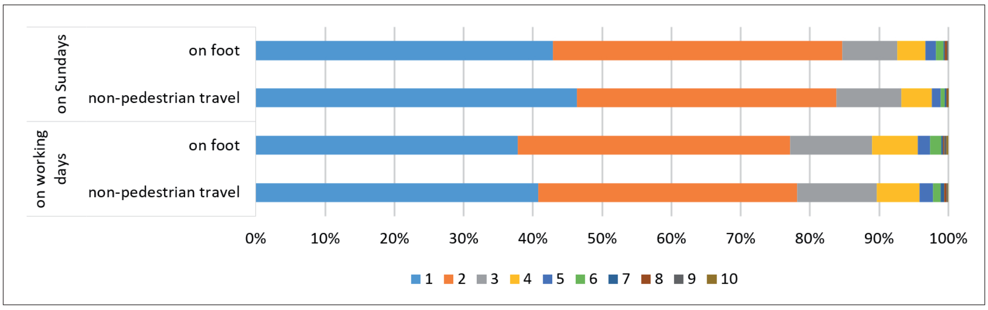

Fig. 5: The proportion of each multi-stage journey in Lodz dependent on the number of trips against the total number of multi-stage journeys on weekdays and Sundays, categorised as pedestrian and non-pedestrian trips in 2021
Source: authors' survey

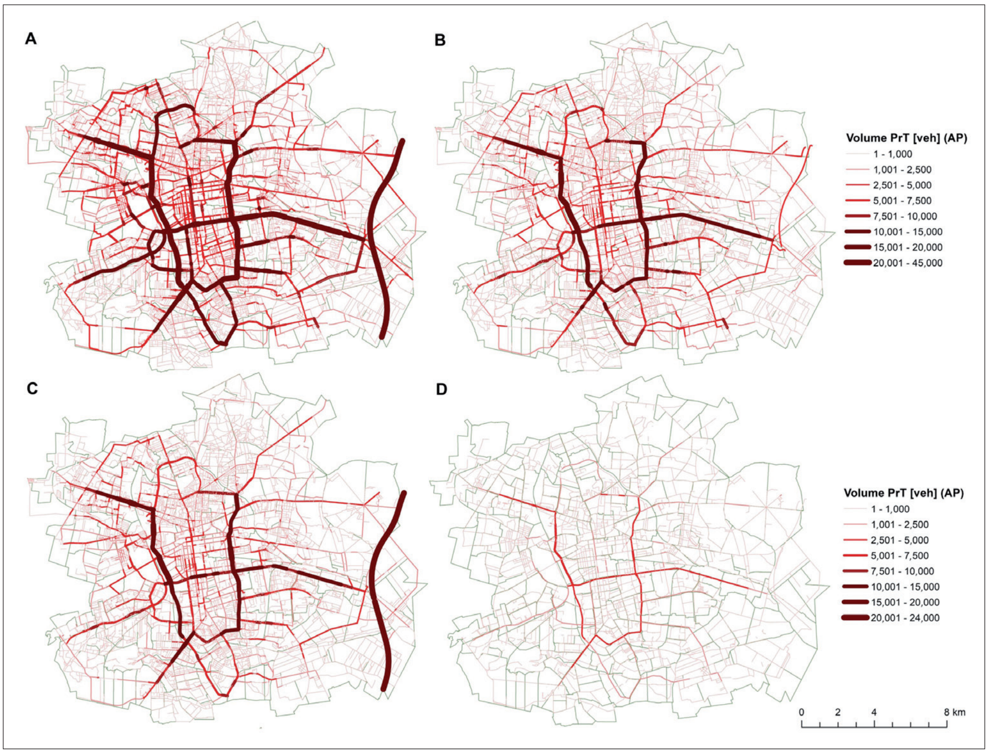

Fig. 6: Flows of private car traffic on the urban road network on weekdays (AB) and Sundays (CD), all internal, origin-external trips, origin-destination and transit trips (AC) and home-work and work-home trips (BD) in Łódź in 2021
Source: authors' survey

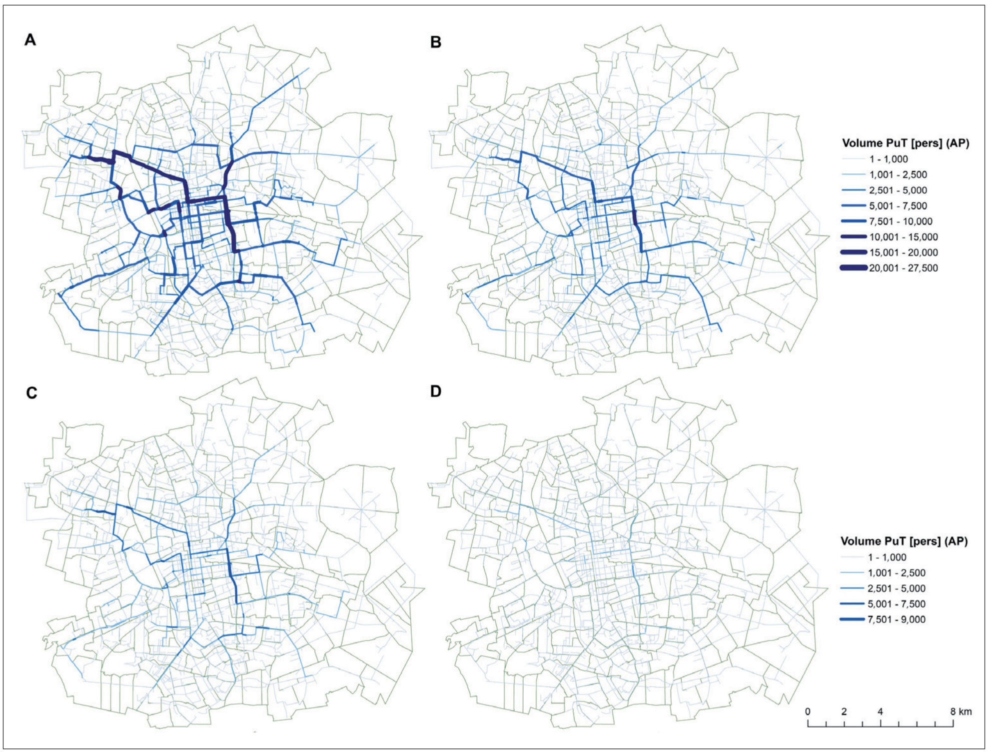

Fig. 7: Numbers and directions of passengers using the urban public transport system in Łódź on weekdays (AB) and Sundays (CD), all internal, origin-external trips, origin-destination and transit trips (AC) and home-work and work-home trips (BD) in 2021
Source: authors' survey

on Sundays compared to working days. The number of home-work and work-home trips using private cars, however, was higher for working days compared to Sundays. The simulated load of the public transport system reveals major traffic flows along the NW-SE axes (Figs. 6 and 7). Furthermore, the simulated traffic load of the public transport system was much higher for working days compared to Sundays (A1–A4).

5.2 Temporal properties of trips

The results of the study indicate considerable diversity in the reasons that travelling is undertaken. While most initial trips made by local residents on weekdays are for commuting to work (54.6%), or less frequently to schools (10.7%) and shopping centres (10.2%), on Sundays Łódź citizens usually make their initial trip to visit family and friends (25.5%), or to satisfy recreational (18.6%) and religious (11.7%) needs, whereas commuting to work accounts for 10.5% of initial trips on Sundays. Diversity is also observed with regards to the time when the initial trip begins, the mode of transport chosen – with a high percentage of trips not involving motorised transport on Sundays (Fig. 8) – and trip duration (a higher percentage of longer trips: Fig. 9). These temporal properties concur with the distribution of daily traffic recorded by inductive loop detectors in 2016 (Kowalski & Wiśniewski, 2017). Investigation of the initial trips on the days in question indicates that Łódź citizens generally use those means of transport that are easily accessible in their temporal dimension (see Tab. 2 below).

5.3 The modal split

The majority of trips in Łódź are made by private car (Tab. 3). These findings differ substantially from the results of studies on the modal structure conducted in Łódź in 1994 (52% public transport, 27% walking, 20% car, and 1% bicycle) (Wójcik, 2020), in 2013 (respectively: 45%, 27%, 25%, and 2%) (City Office, 2013), and in 2014 (respectively: 40%, 39%, 30%, and 3% (including motorcycles)) (City Office, 2014). It is difficult to unequivocally indicate to what extent this high share of car trips is a lasting phenomenon and to what degree it has been temporarily intensified by the pandemic, where people were trying to avoid close contact with crowds. Nevertheless, the aforementioned historical data renders it possible to observe that there is a tendency for an increasing percentage of passenger cars in the daily transport of the city. This modal split of trips in Łódź is extremely unfavourable for the development of sustainable urban transport. The high percentage of passenger cars in daily mobility and the limited role of public transport clearly differentiate Lodz from other large cities in Poland (Fig. 10). Moreover, the high congestion on the roads in Łódź (Borowska-Stefańska et al., 2021) is also partially due to low car occupancy (on working days it is 1.27 persons/vehicle and on Sundays it is 2.01 persons/vehicle), which – given the high share of private cars in the total number of trips – has a profound impact on the efficiency of the road and street transport subsystem (Borowska-Stefańska et al., 2019). The low car occupancy is not a phenomenon specifically attributable to Łódź when compared to other Polish cities (Dębowska-Mróz & Zawisza, 2018; Dudek, 2016).

Mode of Transport	Working Days				Sundays			
	up to 5 minutes	5–10 minutes	10–15 minutes	over 15 minutes	up to 5 minutes	5–10 minutes	10–15 minutes	over 15 minutes
car	96.5%	2.3%	0.5%	0.7%	94.2%	3.9%	0.9%	0.9%
city bus	49.9%	33.2%	13.7%	3.2%	56.0%	33.0%	9.0%	2.0%
tram	52.7%	37.8%	7.9%	1.7%	59.3%	33.0%	6.6%	1.1%

Tab. 2: Walking time to the first transport mode on weekdays and Sundays in Łódź by selected mode of transport in 2021
Source: authors' survey

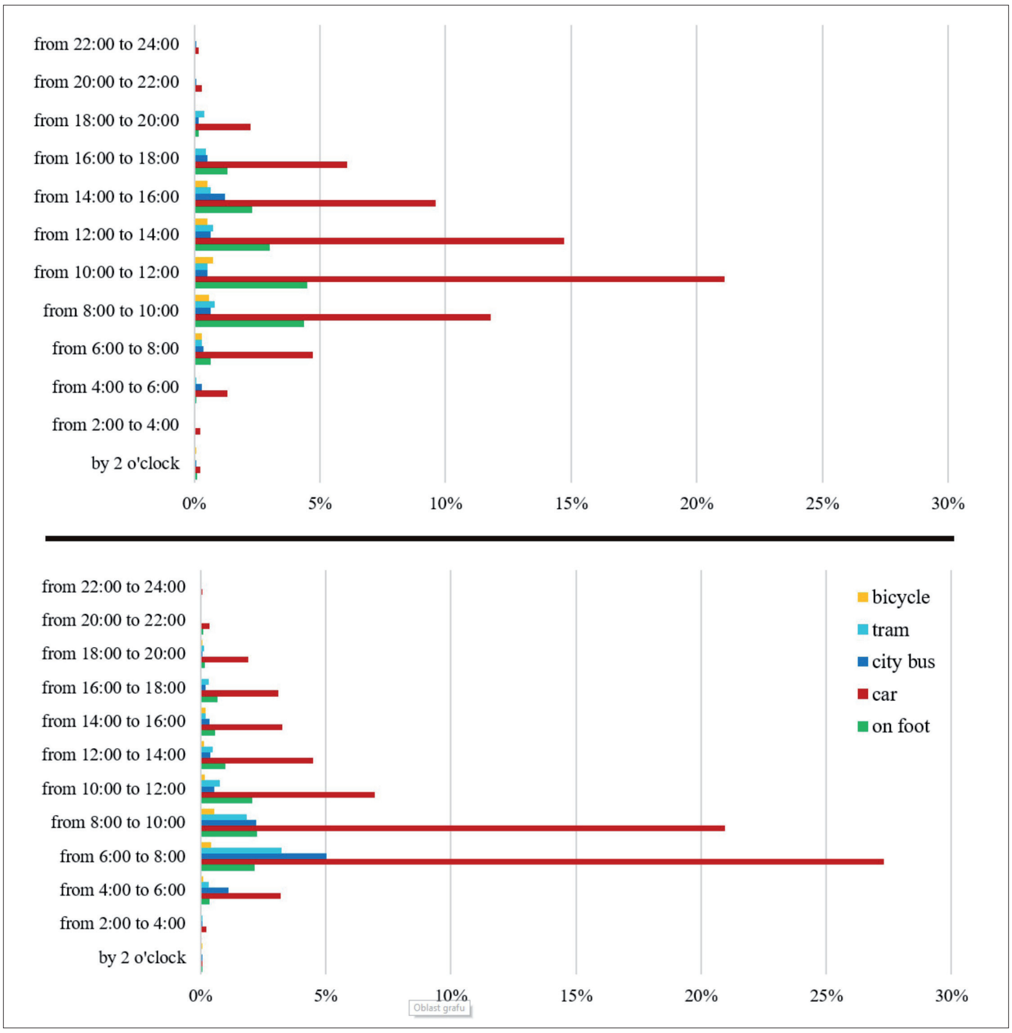

Fig. 8: Temporal differentiation of starting times in Łódź for the initial journey on Sundays (top) and weekdays (bottom) in2021, by selected modes of transport. Source: authors' survey

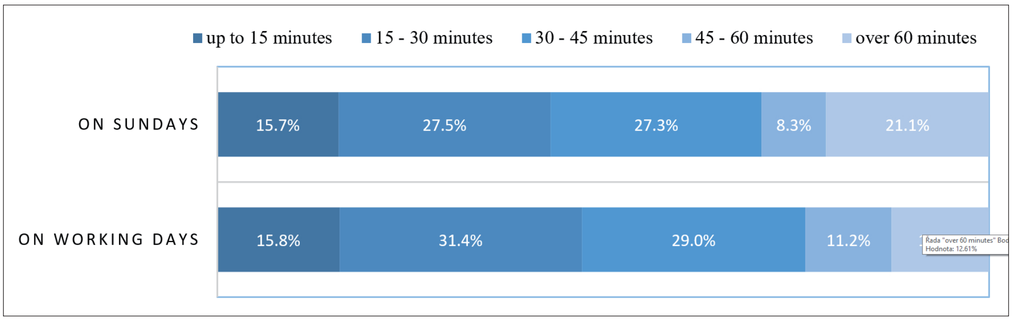

Fig. 9: The structure of trips made on weekdays and Sundays in Łódź in 2021 by trip duration
Source: authors' survey

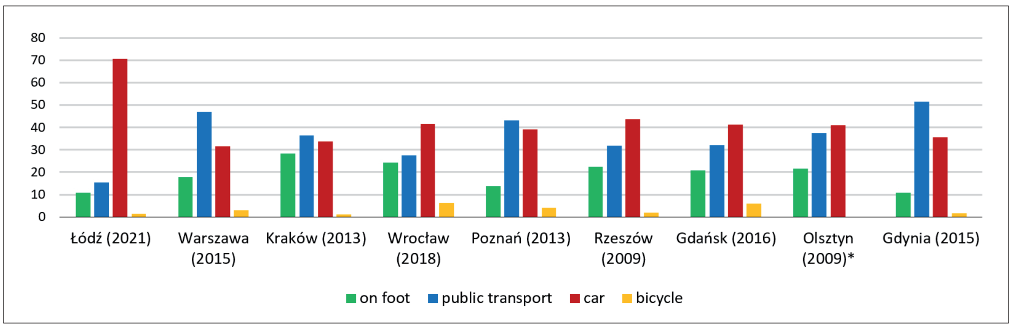

*Fig. 10: The modal split of trips on workdays in selected cities in Poland (Note: *no bike share specified in the surveyed modal split)*
Sources: authors' elaboration based on our research; Szarata (2015); Jacyna et al. (2016); Gadziński (2016); Gadziński and Goras (2019)

Transport mode	Working days (%)	Sundays (%)
Car (as a driver)	65.18	54.61
Only on foot	10.80	16.79
City bus	9.00	4.14
Tram	6.36	3.75
Car (as a passenger)	5.49	15.98
Private bike	1.35	2.13
Taxi or Uber	0.56	0.79
Railway – other	0.24	0.43
Agglomeration railway	0.23	0.30
Interurban bus or coach	0.21	0.20
Motorcycle, scooter, moped	0.18	0.28
Regular special communication	0.11	0.10
Public e-scooter	0.07	0.04
Private scooter	0.04	0.02
Airplane	0.02	0.10
Public bike	0.01	0.10
Refusal to respond	0.14	0.22

Tab. 3: The modal split of trips made on weekdays and Sundays in Łódź in 2021
Source: authors' survey

The share of car use for the most frequent necessary and optional trips made in Łódź is even greater than its percentage within the overall number of journeys. The high proportion of cars in the modal structure of shopping trips is not unique to Łódź when compared to other European cities, with British studies indicating the leading role of the car as the mode of transport chosen for shopping trips (over 62%; and even higher for grocery shopping: 76%) (Guy, 2009). What remains puzzling and worth further analyses is the fact that cars are so commonly used for commuting to work. The modal split of trips in Łódź motivated by employment outside the home is dominated by individual car transport – 82.5%, with 10% for public transport. In the case of shopping and visits to shopping centres, however, the share of individual car transport drops to 65.5%, while the share of trips made by public transport vehicles reaches 23.4%.

6. Conclusions

Conducted in 2021, this study on the transport behaviour of Łódź residents reveals the impact of the implemented Sunday retail restrictions on shopping trips, while importantly, also showing the 'tail-end' of the COVID-19 pandemic. The results were utilised to create a traffic model for the city of Łódź, which – despite being a large urban centre with severe transport issues (e.g. congestion) – possessed no tool of this type (indispensable when performing transport analyses). The results clearly indicate that both the Sunday retail restrictions and the pandemic have had an impact on the travel behaviour of Łódź residents. Similar conclusions regarding changes in mobility in the era of the COVID-19 pandemic come from studies in other cities, countries, or continents (Tarkowski et al., 2020; Batty et al., 2021; Pászto et al., 2021; Simunek, 2021). With respect to the retail restrictions, however, this effect is most evident for shopping trips, which are now made on weekdays or Saturdays instead of Sundays. Moreover, the structure of Sunday trips has changed, as some people have completely stopped travelling on this day, while others have changed their motivations (from shopping in malls to socialising, etc.). Unfortunately, there is still a lack of analyses on the nature of the impact of restrictions in retail trade on mobility. The pandemic, on the other hand, has mainly affected working-day travel (primarily commuting to workplaces), with remote working becoming more popular.

The results of the study can be applied, for instance, to conduct comparative analyses of the impact that the COVID-19 pandemic has had on residents' long-term transport behaviour. The main aim could be to establish whether these changes are permanent or temporary, which would allow the city's transport policies to be more effectively adapted to the challenges of sustainable urban mobility. For the City of Łódź itself, this is all very important, as there has been a noticeable increase in trips in recent years by private means of transport, with a concurrent drop in the popularity of public transport. In this context, the Łódź transport system is very sensitive to further changes in the modal division. Shifts in the modal division towards more frequent use of the car in everyday travel as a result of the pandemic are observed in many parts of the world. As indicated by De Haas et al. (2020) or Jenelius and Cebecauer (2020), for example, because of the pandemic, there was an increase in the use of private cars and non-motorized means of transport (cycling, walking). This was at the expense of public transport, in particular in terms of everyday mobility. Although urban mobility is local in nature, the universality of these changes means that the lack of an appropriate response to this phenomenon may have global consequences, and in this context it may be more difficult to achieve the effects of sustainable mobility (Okraszewska et al., 2018).

The main patterns of changes in the traffic density of the city's road network for individual motivations are determined by the key properties of the trips made for a given motivation. Increases and decreases in the number of vehicles or passenger flows for working days and Sundays typically affect sections of the road network that extend beyond the boundaries of the city district where the traffic generation takes place. This primarily stems from the fact that commuting to work is mainly composed of short trips. Since there is a relatively short distance and travel time between the origin and destination of the trip, there is a spatially limited range of efficient routes. Such distinct changes in vehicle-kilometres are not observed for other motivations when simulating working days and Sunday traffic. Instead, there is a flattening of the increase in vehicle-kilometres. This relationship is not linear, but it is conditioned by a number of factors whose impact varies greatly depending on the motivations and areas of the city. This variability applies to both the transport and land-use components. It is only when these determinants are superimposed that they result in changes in the distribution of traffic over the road network and in the volume of vehicle-kilometres. As regards the transport component, it is not so much the exposure of a particular section of the network that is crucial, but its importance for the implementation of trips for a particular motivation that are taken across the transport regions in the area covered by the simulation. Thus, the aforementioned flattening results from the fact that the volume of the traffic deferred due to a general reduction in the number of trips is reduced. What matters greatly for the simulation of the spatial distribution of changes in the load on the road network is the type of data used to distribute the traffic on the network. The application of matrix data on actual trips motivated by commuting clearly limits the spatial extent of the occurrence of changes in the load of the road network when compared to the model-based approach.

This study of the transport behaviour of the population on working days and Sundays involves the analysis of two extremely complex phenomena. These are of interest to specialists in many scientific fields, and, therefore, should be subject to modelling to ensure that – despite their complexity – they remain predictable, and thus, that their variability can be studied against the labile properties of the system where they operate. Models that map the road network, the variability of car speeds, and the travel paths of people commuting to work make it possible to incorporate multiple factors into the study, along with the complexity of the urban spatial scope. One must also bear in mind, however, that the results obtained from the analyses conducted by using these models may be burdened with the weaknesses typical for them. Even though the focus was solely on transport behaviour, with no dedicated research on social or economic backgrounds, the analysed properties of changes in behaviour between working days and Sundays returns a wide range of results. Conducting extensive direct research is considered in most countries as one of the basic elements of creating transport policy and is a precondition for rational spending of public funds (Dziedzic & Szarata, 2014). In the case of research related to the transport behaviour of residents of a large city, the research period selected in the work was particularly important, because it was associated with two factors affecting it – on the one hand, it was the Trade Act and on the other hand, the pandemic. This is important because the pandemic is a global phenomenon – so its impact on transport behaviour and the conclusions drawn from it can be used not only in the city where the research was conducted. The same, although on a smaller scale, applies to research related to Sunday retail restrictions. In Europe, some countries also have such restrictions (Genakos & Danchev, 2015) and there is still little research on their impact on the mobility of the population.

Acknowledgements

The article was written under the project No. 2019/35/D/HS4/00697 funded by the National Science Centre in Poland. The project is co-financed by the Polish National Agency for Academic Exchange and under the framework of the 2% subsidy for tertiary education aimed at academies and universities which participated in the IDUB Contest ('Inicjatywa Doskonałości – Uczelnia Badawcza').

References:

Axhausen, K. W., Zimmermann, A., Schönfelder, S., Rindsfüser, G. & Haupt, T. (2002). Observing the rhythms of daily life: A six-week travel diary. Transportation, 29(2), 95–124. https://doi.org/10.1023/A:1014247822322

Barceló, J. (2010). Models, traffic models, simulation, and traffic simulation, In: J. Barceló (Ed.), Fundamentals of Traffic Simulation (pp. 1–62). Springer. www.dx.doi.org/10.1007/978-1-4419-6142-6

Bartuska, L., Stopka, O., Hanzl, J., Sedivy, J., & Rybicka, I. (2022). Changes in transport behaviour of the Czech population caused by state of emergency, Transport problems, 17(1), 101–115. www.dx.doi.org/10.20858/tp.2022.17.1.09

Batty, M., Murcio, R., Iacopinii, I., Vanhoof, M., & Milton, R. (2021). London in lockdown: Mobility in the pandemic city. In A. Rajabifard, D. F. Paez, & G. Foliente (Eds.), COVID-19 pandemic, Geospatial Information, and Community Resilience (pp. 229–244). CRC Press. https://doi.org/10.1201/9781003181590

Ben-Akiva, M. E. & Lerman, S. R. (1985). Discrete choice analysis: theory and application to travel demand, Ben-Akiva, M. E. & Lerman, S. R. (1985). Discrete choice analysis: theory and application to travel demand Volume 9. MIT press. https://doi.org/10.2307/1391567

Boarnet, M. G. & Crane, R. (2001). Travel by design the influence of urban form on travel. Oxford University Press Inc. https://doi.org/10.1093/oso/9780195123951.001.0001

Boarnet, M., & Sarmiento, S. (1998). Can land-use policy really affect travel behavior? A study of the link between non-work travel and land-use characteristics, Urban studies, 35(7), 1155–1169. https://doi.org/10.1080/0042098984538

Borowska-Stefańska, M., Kowalski, M., Kurzyk, P., Mikušová, M., & Wiśniewski, S. (2021). Application of Intelligent Transportation Systems in Analyses of Human Spatial Mobility in Cities. Prace Komisji Geografii Komunikacji PTG, 24(1), 7–30. www.dx.doi.org/10.4467/2543859XPKG.21.001.14944

Borowska-Stefańska, M., Kowalski, M., Kurzyk, P., Sahebgharani, A., Sapińska, P., Wiśniewski, S., Goniewicz, K., & Dulebenet, M. A. (2022b). Assessing the Impacts of Sunday Trading Restrictions on Urban Public Transport: an Example of a Big City in Central Poland in review.

Borowska-Stefańska, M., Kowalski, M., Kurzyk, P., Sahebgharani, A., & Wiśniewski, S. (2022a). Spatiotemporal Changeability of the Load of the Urban Road Transport System under Permanent and Short-Term Legal and Administrative Retail Restrictions. Sustainability, 14(9), 5137. https://doi.org/10.3390/su14095137

Borowska-Stefańska, M., Kowalski, M., Maczuga, M., Szustowski B., & Wiśniewski, S. (2020). Public transport in a big Polish city (as exemplified by Łódź) in the opinion of older persons. Prace Komisji Geografii Komunikacji PTG, 23(3), 15–28. www.dx.doi.org/10.4467/2543859XPKG.20.017.12785

Bovy, P. H., & Stern, E. (2012). Route choice: Wayfinding in transport networks: Wayfinding in transport networks Studies in Operational Regional Science, 9. Springer Dordrecht. https://doi.org/10.1007/978-94-009-0633-4

Bruns, A., & Matthees, G. (2019). Moving into and within cities – Interactions of residential change and the travel behavior and implications for integrated land use and transport planning strategies, Travel Behaviour and Society 17, 46–61. https://doi.org/10.1016/j.tbs.2019.06.002

Button, K. J., & Hensher, D. A. (2005). Handbook of Transport Strategy, Policy and Institutions, 6. Emerald Group Publishing Limited, https://doi.org/10.1108/9780080456041-001

Cao, J., & Ermagun, A. (2016). Influences of LRT on travel behaviour: a retrospective study on movers in Minneapolis. Urban Studies, 54(11), 2504–2520. https://doi.org/10.1177/0042098016651569

Cao, J., Mokhtarian, P. L., & Handy, S. L. (2009). Examining the impacts of residential self-selection on travel behaviour: a focus on empirical findings. Transport Reviews, 29(3), 359–395. https://doi.org/10.1080/01441640802539195

Central Statistical Office (2015). Badanie pilotażowe zachowań komunikacyjnych ludności w Polsce. badanie_pilotazowe_zachowan_komunikacyjnych_ludnosci_w_polsce.pdf

Cordera, R., Coppola, P., & Ibeas, Á. (2017). Is accessibility relevant in trip generation? Modelling the interaction between trip generation and accessibility taking into account spatial effects. Transportation, 44(6), 1577–1603. https://doi.org/10.1007/s11116-016-9715-5

De Haas, M., Faber, R., & Hamersma, M. (2020). How COVID-19 and the Dutch 'intelligent lockdown' change activities, work and travel behaviour: Evidence from longitudinal data in the Netherlands. Transportation Research Interdisciplinary Perspectives, 6, 100150. https://doi.org/10.1016/j.trip.2020.100150

De Vos, J., Ettema, D., & Witlox, F. (2018). Changing travel behaviour and attitudes following a residential relocation. Journal of transport geography, 73, 131–147, https://doi.org/10.1016/j.jtrangeo.2018.10.013

De Vos, J., & Witlox, F. (2013). Transportation policy as spatial planning tool; reducing urban sprawl by increasing travel costs and clustering infrastructure and public transportation. Journal of transport geography, 33, 117–125. https://doi.org/10.1016/j.jtrangeo.2013.09.014

De Vos, J., & Witlox, F. (2016). Do people live in urban neighbourhoods because they do not like to travel? Analysing an alternative residential self-selection hypothesis. Travel Behaviour and Society, 4, 29–39. https://doi.org/10.1016/j.tbs.2015.12.002

Dębowska-Mróz, M., & Zawisza, T. (2018). Ocena zróżnicowania napełnienia samochodów osobowych wykorzystywanych do realizacji przemieszczeń w miastach. Autobusy–Technika, Eksploatacja, Systemy Transportowe, 226(12), 382–385. http://ojs.inw-spatium.pl/index.php/Autobusy/article/view/825

Dudek, M. (2016). Analiza zmienności napełnień samochodów osobowych na wlotach do dużego miasta na przykładzie zachodniej części Krakowa. Transport Miejski i Regionalny, 6, 12–15. http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-e9748c2f-95db-40a4-a98e-6cdb4485fdca/c/TMiR_6_2016_Dudek.pdf

Dziedzic, T., & Szarata, A. (2014). Wybrane wyniki kompleksowych badań ruchu w województwie małopolskim. Transport Miejski i Regionalny, 1, 30–34. http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-a88fd3b2-836f-4c34-a1c0-2451016e7948

Engle, S., Stromme, J., & Zhou, A. (2020, April 3). Staying at home: mobility effects of covid-19. Health Economics eJournal. http://dx.doi.org/10.2139/ssrn.3565703

Ewing, R., & Cervero, R. (2010). Travel and the built environment. A meta-analysis, Journal of the American planning association, 76(3), 265–294. http://dx.doi.org/10.1080/01944361003766766

Fielbaum, A., Jara-Diaz, S., & Gschwender, A. (2017). A parametric description of cities for the normative analysis of transport systems. Networks and Spatial Economics, 17(2), 343–365. https://link.springer.com/article/10.1007/s11067-016-9329-7

Fierek, S., & Zak, J. (2012). Planning of an integrated urban transportation system based on macro-simulation and MCDM/A methods. Procedia-Social and Behavioral Sciences, 54, 567–579. https://doi.org/10.1016/j.sbspro.2012.09.774

Gadziński, J. (2016). Wpływ dostępności transportu publicznego na zachowania transportowe mieszkańców – przykład aglomeracji poznańskiej. Prace Komisji Geografii Komunikacji PTG, 19(1), 31–42. http://dx.doi.org/10.4467/2543859XPKG.16.003.6301

Gadziński, J., & Goras, E. (2019). Jak zmieniła się codzienna ruchliwość mieszkańców polskich miast? 50 lat badań zachowań transportowych ludności w Polsce. Prace Komisji Geografii Komunikacji PTG, 22(4), 8–24. http://dx.doi.org/10.4467/2543859XPKG.19.019.11540

Gadziński, J., & Radzimski, A. (2015). The first rapid tramline in Poland: How has it affected travel behaviours, housing choices and satisfaction, and apartment prices? Journal of Transport Geography, 54, 451–463. https://doi.org/10.1016/j.jtrangeo.2015.11.001

Genakos, C., & Danchev, S. (2015). Evaluating the Impact of Sunday Trading Deregulations. Discussion Paper No. 1336, March 2015. Centre for Economic Performance, London School of Economics. https://cep.lse.ac.uk/pubs/download/dp1336.pdf

Guy, C. (2009). 'Sustainable transport choices' in consumer shopping: a review of the UK evidence. International Journal of Consumer Studies, 33, 652–658. https://doi.org/10.1111/j.1470-6431.2009.00818.x

Handy, S. L. (1996). Understanding the link between urban form and nonwork travel behaviour. Journal of planning education and research, 15(3), 183–198. https://doi.org/10.1177/0739456X9601500303

Hass-Klau, C., & Crampton, G. (2002). Future of Urban Transport: Learning from Success and Weaknesses: Light Rail. Environmental and Transport Planning. Bergische Universität Wuppertal.

Horbachov, P., Makarichev, O., Svichynskyi, S. & Ivanov, I. (2022). Framework for designing sample travel surveys for transport demand modelling in cities. Transportation, 49(1), 115–136. https://doi.org/10.1007/s11116-021-10168-6

Institute of Statistics of the Catholic Church (2021). Annuarium statisticum ecclesiae in Polonia. https://misericors.org/tag/raport-iskk-za-2021-rok/

Jacyna, M., Wasiak, M. & Gołębiewski, P. (2016). Model ruchu rowerowego dla Warszawy według Warszawskiego Badania Ruchu 2015. Transport Miejski i Regionalny. https://bibliotekanauki.pl/articles/953146

Jamroz, K., Birr, K., Grulkowski, S., Kalkowski, K. & Budziszewski T. (2014). Analiza możliwości wzrostu udziału transportu zbiorowego w wojewódzkich przewozach pasażerskich na przykładzie województwa pomorskiego. Transport Miejski i Regionalny.

Jenelius, E. & Cebecauer, M. (2020). Impacts of COVID-19 on public transport ridership in Sweden: Analysis of ticket validations, sales and passenger counts. Transportation Research Interdisciplinary Perspectives, 8, 100242. https://doi.org/10.1016/j.trip.2020.100242

Karoń, G., Mikulski, J. (2013). Forecasts for Technical Variants of ITS Projects – Example of Upper-Silesian Conurbation. In J. Mikulski, (Ed.), Activities of Transport Telematics. TST 2013 (pp. 67–74). Communications in Computer and Information Science, vol. 395. Springer. https://doi.org/10.1007/978-3-642-41647-7_9

Kockelman, K. (1997). Travel behaviour as function of accessibility, land use mixing, and land use balance: evidence from San Francisco Bay Area. Transportation Research Record. Journal of the Transportation Research Board, 1607(1), 116–125. https://doi.org/10.3141/1607-16

Kowalski M. & Wiśniewski S. (2017). Natężenie ruchu a zagospodarowanie Łodzi – zarys problematyki w świetle danych z Obszarowego Systemu Sterowania Ruchem. Prace Komisji Geografii Komunikacji Polskiego Towarzystwa Geograficznego, 20(4), 20–36. https://doi.org/10.4467/2543859XPKG.17.022.8028

Lane, B. W. (2008). Significant characteristics of the urban rail renaissance in the United States: A discriminant analysis. Transportation Research: Part A: Policy and Practice, 42(2), 279–295. https://doi.org/10.1016/j.tra.2007.10.001

Liepmann, K. K. (1945). The Journey to work. Kegan, Trench, Trubner.

Martin, S., & Bergman, J. (2021). (Im)mobility in the age of COVID-19. International Migration Review, 55(3), 660–687. https://doi.org/10.1177/0197918320984

Meyer, D. M. (2016). Transport Planning Handbook. John Wiley & Sons. https://users.pfw.edu/sahap/CE450%20Transport%20Policy%20and%20Planning/1.%20Lectures/Books%2C%20references%2C%20readings/Transportation%20Planning%20Handbook%20Forth%20Edition.pdf

Mitchell R. B, & Rapkin, C. (1954). Urban Traffic: A Function of Land Use. Columbia University Press. https://doi.org/10.7312/MITC94522

Okraszewska, R., Romanowska, A., Wołek, M., Oskarbski, J., Birr, K., & Jamroz, K. (2018). Integration of a multilevel transport system model into sustainable urban mobility planning. Sustainability, 10(2), 479. https://www.mdpi.com/2071-1050/10/2/479. https://doi.org/10.3390/su10020479

Pászto, V., Burian, J., & Macku, K. (2021). Changing mobility lifestyle: A case study on the impact of COVID-19 using personal google locations data. International Journal of E-Planning Research, 10(2), 66–79. https://doi.org/10.4018/IJEPR.20210401.oa6

Proost, S., & Van Dender, K. (2001). The welfare impacts of alternative policies to address atmospheric pollution in urban road transport. Regional Science and Urban Economics, 31(4), 383–411. https://doi.org/10.1016/S0166-0462(00)00079-X

Rixey, R. A. (2013). Station-Level Forecasting of Bikesharing Ridership: Station Network Effects in Three U.S. Systems. Transportation Research Record, 2387(1), 46–55. https://doi.org/10.3141/2387-06

Rogulski, M., & Badyda, A. (2021). Air pollution observations in selected locations in Poland during the lockdown related to COVID-19. Atmosphere, 12(7), 806. https://www.mdpi.com/2073-4433/12/7/806. https://doi.org/10.3390/atmos12070806

Sayed, T., & Razavi, A. (2000). Comparison of neural and conventional approaches to mode choice analysis. Journal of Computing in Civil Engineering, 14(1), 23–30. https://doi.org/10.1061/(ASCE)0887-3801(2000)14:1(23)

Sawicki, P., Kiciński, M., & Fierek, S. (2016). Selection of the most adequate trip-modelling tool for integrated transport planning system. Archives of Transport, 37(1), 55–66. https://doi.org/10.5604/08669546.1203203

Schlosser, F., Maier, B. F., Jack, O., Hinrichs, D., Zachariae, A., & Brockmann, D. (2020). COVID-19 lockdown induces disease-mitigating structural changes in mobility networks. Proceedings of the National Academy of Sciences, 117(52), 32883–32890. https://doi.org/10.1073/pnas.2012326117

Schneider, R. J., Shafizadeh, K., & Handy, S. L. (2015). Method to adjust Institute of Transportation Engineers vehicle trip-generation estimates in smart-growth areas. Journal of Transport and Land Use, 8(1), 69–83. https://doi.org/10.5198/jtlu.2015.416

Shibayama, T., Sandholzer, F., Laa, B., & Brezina, T. (2021). Impact of COVID-19 lockdown on commuting: A multi-country perspective. European Journal of Transport and Infrastructure Research, 21(1), 70–93. https://doi.org/10.18757/ejtir.2021.21.1.5135

Simunek, M., Smutny, Z., & Dolezel, M. (2021). The impact of the COVID-19 movement restrictions on the road traffic in the Czech Republic during the state of emergency. Journal of advanced transportation, 2021, 1–20. https://doi.org/10.1155/2021/6622028

Stevens, M. R. (2017). Does compact development make people drive less? Journal of the American Planning Association, 83(1), 7–18. https://doi.org/10.1080/01944363.2016.1240044

Stopher, P. R. (1992). Use of an activity-based diary to collect household travel data. Transportation, 19(2), 159–176. https://doi.org/10.1007/BF02132836

Szarata, A. (2015). Wyniki badań podróży w Krakowie–KBR 2013. Transport Miejski i Regionalny 5/2015, 4–8. https://tmir.sitk.org.pl/wp-content/uploads/2018/08/gazeta05_2015_druk.pdf.

Tarkowski, M., Puzdrakiewicz, K., Jaczewska, J., & Połom, M. (2020). COVID-19 lockdown in Poland–changes in regional and local mobility patterns based on Google Maps data. Prace Komisji Geografii Komunikacji PTG, 23(2), 46–55. https://doi.org/10.4467/2543859XPKG.20.007.12105

Transport Behaviour among Residents of Large Cities (2021). Zachowania transportowe mieszkańców dużych miast, Główne wyniki badań wzorów zachowań transportowych mieszkańców dużych polskich miast zrealizowanych w I kwartale 2021 r. https://polskialarmsmogowy.pl/wp-content/uploads/2021/06/Raport_zachowaniatransportowe_miasta_skrot1.pdf

Van Acker, V., Van Wee, B., & Witlox, F. (2010). When Transport Geography Meets Social Psychology: Toward a Conceptual Model of Travel Behaviour, Transport Reviews, 30(2), 219–240. https://doi.org/10.1080/01441640902943453

Van de Coevering, P., Maat, K., & Van Wee, B. (2018). Residential self-selection, reverse causality and residential dissonance. A latent class transition model of interactions between the built environment, travel attitudes and travel behaviour. Transportation Research Part: A Policy and Practice, 118, 466–479, https://doi.org/10.1016/j.tra.2018.08.035.

Wang, D., & Lin, T. (2017). Built environment, travel behaviour, and residential self-selection: a study based on panel data from Beijing, China. Transportation, 46(1), 51–74. https://doi.org/10. 1007/s11116-017-9783-1.

Wismans, L., De Romph, E., Friso, K., & Zantema, K. (2014). Real time traffic models, decision support for traffic management. Procedia Environmental Sciences, 22, 220–235. https://doi.org/10.1016/j.proenv.2014.11.022

Wójcik, S. (2020). Determinanty zachowań transportowych mieszkańców Łodzi. Wydawnictwo Uniwersytetu Łódzkiego. https://wydawnictwo.uni.lodz.pl/produkt/determinanty-zachowan-transportowych-mieszkancow-lodzi/

Zhang, Y., Zhao, P. & Lin, J. J. (2021). Exploring shopping travel behavior of millennials in Beijing: Impacts of built environment, life stages, and subjective preferences. Transportation Research: Part A Policy Practice, 147, 49–60. https://doi.org/10.1016/j.tra.2021.03.012

Please cite this article as:

Wiśniewski, S., Borowska-Stefańska, M., Dulebenets, M., Kowalski, M., & Masierek, E. (2023). Changeability of transport behaviour in a large city from the perspective of working days and Sundays: The case of Łódź, Poland. Moravian Geographical Reports, 31(1), 14–26. https://doi.org/10.2478/mgr-2023-0002