

Depopulation or ageing? Decomposing the aggregate effects of projected demographic changes on urban transport systems

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ABSTRACT

Many developed and developing countries are experiencing rapid demographic changes in the form of ageing and depopulation. These processes influence many areas of the economy and are likely to affect the transport behaviours of residents and thus the development of public transport systems. In this study, we combine estimates of age-related determinants of individuals' transport behaviour with demographic projections for the next 30 years to draw quantitative conclusions on the effect of ongoing demographic processes on the transport system. The study is based on data from a large household survey ($N = 23,975$) conducted in 15 municipalities in the central part of Silesia Province, which is one of the largest metropolitan areas in Central Europe. This industrialized region is projected to experience particularly rapid demographic changes as global demographic trends will be reinforced by depopulation and suburbanization resulting from decarbonization and the green transformation of the local economy. The results clearly show that depopulation will be the main demographic force influencing the transport system in the region studied, while the impact of ageing is limited. For example, the former is expected to decrease the total number of journeys by 30% up to 2050, while the latter will do so only by <4%. We also find a weak impact of ageing on journey structure by modes of transport.

1. Introduction

Demographic changes are an important factor in economic development. Forecasts for European countries indicate that the main ongoing trends of population decline and population ageing will lead to significant, negative consequences for the economy. Demographic forecasts show that in relation to 2019, by 2026 the population in the European Union (EU-27) will have decreased by approximately 1.3%, and by 2100 by almost 7% (Eurostat, 2020). The data indicates that this change in the population will not proceed as fast as the changes in the age structure, which result from increasing life expectancy and migration to the EU. The intensity of depopulation varies widely across the EU-27, even at the regional level (despite the overall decline in a country's population, some regions will see an increase). Compared to other European countries, Poland will face significant depopulation. Forecasts show that by 2050, the population will have decreased by 10.9% compared to 2020 (Statistics Poland, 2014).

The ageing of the population is a global trend, especially in Europe. The definition of older adults varies across the research literature. The World Health Organization (WHO) defines the elderly (older people) as

people over the age of 65, and also distinguishes the category of oldest-old, which includes people aged 85+ (WHO, 2008). The majority of research papers follow the definition of the WHO, and adopt the age of 65. The increase in the share of older people in the population is most often due to two factors: a drop in the number of births, which leads to a decrease in the share of the youngest age groups, and an increase in life expectancy, which results from the development of medicine and continuous improvement of living conditions. In 2019, the share of people aged over 65 in the population of the EU-27 was 20.3%, which was an increase of 2.9 p.p. compared to 2009 (Eurostat, 2020). In the case of Poland, this increase was by 4.2 p.p. (from 13.5% to 17.7%). Eurostat data also shows a decline in the number of people of pre-working age (0–14), and in the number of people of working age (15–64) in Europe. In the EU-27, the share of people aged 65 years or more in the total population is projected to increase to 30.3% by 2070. Also, the share of persons aged over 80 will dynamically increase from 5.8% in 2019 to 13.2% in 2070. The share of people aged 65+ in Poland is expected to be about 32.7% by 2050 (Statistics Poland, 2014). The European Commission has identified several key areas affected by the ageing of society: the labour market, health and long-term care, public

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budgets, quality of life, infrastructure and access to services (European Commission, 2020).

The main aim of the study is to examine the impact of the expected demographic changes, especially ageing and depopulation, on aggregate transport behaviour, characterized by the daily number of trips and the modal split in the Silesia province. We employ a two-step procedure. First, we use data from a large household survey ($N = 23,975$ respondents) on transport behaviour to identify the relationships between age and age-related factors and the transport behaviours of respondents. Then, we merge the results with the demographic projection for the area under investigation to measure the aggregate consequences of the expected demographic changes for transport behaviour. In particular, we separately assess the impacts of the decreasing population and the changes in its age structure to check which of the two processes is likely to influence the aggregate transport behaviour characteristics more. One of the results of the first step of the procedure is a set of complete theoretical age profiles for the daily number of trips and the modal split. Contrary to many other studies, the profiles cover not only older adults but other age groups as well, including children and adolescents, since the demographic changes affect the entire age structure of a population.

The paper is organized as follows: Section 2 presents a review of the literature on older adults' mobility. This section is focused primarily on the results of research papers on the level of mobility of older adults, and on the relationship between ageing and car use. Section 3 presents the data, the characteristics of the study area and the applied methods. Section 4 contains the research results. Section 5 discusses the findings, strengths and limitations of the research, and demonstrates the implications for transport policy.

2. Literature review

The mobility of older adults (over the age of 65) has been studied from different perspectives. The main research perspectives are as follows: functional limitations and disability (Christensen et al., 2009; Whelan et al., 2006); accessibility and barriers in a built environment and modes of transport (Risser et al., 2010; Nordbakke, 2013; Chudyk et al., 2015; Cao et al., 2010), and the perspective of travel behaviours and mobility patterns. The analysis of previous research results demonstrates that the group of older people is heterogeneous in terms of the level of mobility and travel behaviours (Siren and Haustein, 2013; Su and Bell, 2012). Numerous studies conducted so far have been focused on the travel behaviours and mobility of older adults (Table 1).

According to Hensher (2007) the mobility of people over 65 decreases significantly compared to other age groups (Hensher, 2007). Webber et al. (2010) indicate that older people's mobility is influenced by many aspects, including environmental, financial, psycho-social, physical and cognitive factors. Travel activity and mode choice in this age group is also influenced by the accessibility to public or private transport (Smith and Sylvestre, 2001), income level (Truong and Somenahalli, 2011; Ryan et al., 2019) and living neighbourhood (Chudyk et al., 2015; Figueroa et al., 2014; Cao et al., 2007). According to Chudyk et al. (2015), living in areas with a greater prevalence of destinations is positively associated with the biggest share of walking and, as indicated by Cao et al. (2010), with physical activity of elderly people.

The general mobility of older people has increased over time (Banister and Bowling, 2004; O'Fallon and Sullivan, 2009; Buehler and Nobis, 2010; Toole-Holt et al., 2005; Yang et al., 2018). However, it is observed that the older people's mobility is significantly lower than in younger age groups. It can be measured by the number of trips and travel distance. From Table 1, it can be seen that the results of studies conducted so far show that older adults make fewer and shorter trips than younger groups (Hensher, 2007; O'Fallon and Sullivan, 2009; Buehler and Nobis, 2010). The survey carried out by the Dutch Ministry of Transport in 2001 shows that in the age group of 50–64, the number of daily journeys is 3, in the age 65–74 it ranges between 2.3 (women) and 2.7 (men), while in the 75+ age group, it falls below 2 (EMTA, 2007).

Table 1

Review of research results on the level of mobility of older adults (selected studies).

Author(s)	Country/location	Main results of the study
O'Fallon and Sullivan (2009)	New Zealand	The general mobility of older people has increased over time. People aged 60+ demonstrated lower mobility parameters compared with younger groups. They made fewer and shorter trips as vehicle drivers, but more and longer trips as vehicle passengers or pedestrians.
Buehler and Nobis (2010)	USA and Germany	In the oldest age group of people over the mobility increased significantly. The number of people who did not make any trips decreased and the daily distance travelled increased. The use of private car in this age group increased. However, this age group was characterized by the lowest level of mobility compared to the other age groups.
Currie and Delbosc (2010)	Victoria (Australia)	People aged 60+ demonstrated 30% lower level of mobility and 16% lower public transport usage.
Truong and Somenahalli (2011)	Adelaide (Australia)	The results of analyses were presented for three age groups: 65–74, 75–84 and 85+. The daily number of trips and their distance decrease with age. In the 85+ group, the share of people who do not make any trips increased significantly. The research also showed a positive correlation between the level of income and the number of trips.
Haustein et al. (2013)	Germany	The percentage of mobile persons, daily travel time, distance in km per day, and number of trips per day for people aged 65+ were significantly lower than in younger groups.
Liu et al. (2017)	Beijing (China)	The average travel distance of the middle-aged/young group was 7 km, and the average travel duration was 39 min. In the elderly group, the average travel distance and average travel duration was much shorter - 3.2 km and 28.4 min respectively. The frequency of travel in this age group was also significantly lower than in younger groups.
Yang et al. (2018)	USA	In the group aged 65+, in comparison with people aged 45–65, the number of daily trips and travel distance significantly decreases. The number of destinations and share of public transport in serving mobility have also decreased together with age.

The National Household Travel Survey conducted in USA in 2009 indicated that in the age group of 65+, the number of daily trips decreases to the level of 3.3 of trips per day in comparison to over 4 trips in the age group 45–65. Liu et al. (2017) indicate that the average travel distance of the elderly group is twice lower than in the middle-aged/young group.

Furthermore, the importance of leisure and social category trips is increasing with age, as a natural consequence of decreasing the role of professional activity and obligatory needs (King et al., 2003; O'Fallon and Sullivan, 2009; Haustein et al., 2013).

The results concerning car use by older people are highly varied. There are studies showing that car (passenger and driver) was dominating in the travel structure of older people (Boschmann and Brady, 2013; Newbold et al., 2005; Luiu et al., 2018; Siren and Haustein (2013)). Car access and the opportunity to drive a private car is very important for older people's mobility, as it can compensate for functional limitations resulting from ageing (Siren and Hakamies-Blomqvist, 2004). Private car use is also associated with higher life satisfaction and

social activity (Banister and Bowling, 2004; Haustein et al., 2013; Pristavec, 2016). The decrease of demand for public transport in favor of private cars is a feature of the contemporary societies. The use of private cars grows with age, and with the increase of income and standard of living (Hensher and Prioni, 2002; Hildebrand, 2003; Bardazzi and Pazienza, 2018). On the other hand, empirical evidence shows that the use of car decreases with age, which can be associated with retirement and the decline of work-related journeys (O'Hern and Oxley, 2015; Hjorthol et al., 2010); lower income (Liu et al., 2017), or age-related impairments influencing the capability to drive (Box et al., 2010; Dit et al., 2014). The results of study conducted by Raitanen et al. (2003) in Finland ($n = 618$), Germany ($n = 804$) and Italy ($n = 600$) among participants over the age of 55 show that reduction of driving with age is a common phenomenon. The main reasons of driving reduction include being able to reach a destination without a car, health impairments and difficulties in finding parking spaces (Raitanen et al., 2003).

Another very important part of research focuses on the influence of demographic changes on the transport system. Spielberg and Andrlé (1982) studied demographic changes in the period from 1960 to 1980, with some projections to 2000 in the USA. They analysed the structure of the population, average household size and household composition and economic factors. They also looked into the resulting effects on the transport system and transport policy implications in suburban areas and city centres. Despite the fact that the data and projections relate to the past, this study has led to important accurate conclusions that are also reasonably valid today (Table 2).

The results of studies conducted by Spielberg and Andrlé (1982) and Ahrens (2005) show that the ongoing process of suburbanization will lead to greater car-dependency. On the one hand, the decrease in fertility could slow urban sprawl, but on the other hand, suburbs will absorb the growth in population and attract families with children. Studies conducted so far in this field show a pressing need to adapt the urban transport system to the changing demographic structure. There is a need for a more evidence-based transport policy to introduce new services adjusted to the need of older adults, redesign the whole system and rethink current investments (Ahrens, 2005; Mercado et al., 2010; Driscoll et al., 2018; Pomoni et al., 2020; Pettersson and Schmöcker, 2010; Hylton, 2016).

An extensive body of studies has investigated the impact of age and age-related factors on transport behaviour, but not many have examined the long-term influence of demographic changes on future transport systems in cities. According to Schwanen and Páez (2010), issues concerning relations between the transport system, land use and ageing are of undeniable importance.

This study focuses not only on ageing, but also on the process of depopulation, which is strongly related to ageing but is much broader and complex as it includes, among others, population migration and the process of suburbanization (Alamá-Sabater et al., 2021). In the existing literature, the process of depopulation has not been studied. This research complements previous theoretical output in this area and sheds new light on the consequences of these demographic changes on transport policy and urban planning.

Furthermore, the vast majority of studies come mainly from Western Europe, North America or Australia. The need to extend research to other countries outside the Western world has been pointed out i.e. by Schwanen and Páez (2010) or Pettersson and Schmöcker (2010). This paper offers a new point of view by introducing the results of research on the impact of demographic changes on transport systems in Poland. Similarly to other countries in Eastern Europe, Poland is on the one hand a dynamically developing young market economy with a car-oriented mobility culture. On the other hand, it is a country where cities and public transport systems are developing dynamically, with the aspiration of shaping sustainable urban transport systems in the future.

The main research questions addressed in this study are:

Table 2

Review of research results on the influence of changes in demographic structure on the transport system (selected studies).

Author(s)	Country/location	Main results of the study
Spielberg and Andrlé (1982)	USA	Suburban areas will absorb most of the growth in population and households without commensurate increases in the capacity of the road infrastructure and the quality of public transport. Increasing use of private cars. Congestion inevitable. In city centres – the decrease in households with children will result in the need to reorganise public spaces and the transport system toward the needs of adults and older adults. In central cities, policies will be oriented toward providing affordable mobility for less affluent citizens who remain in the city centres.
Metz (2003a, 2003b)	UK	A variety of measures is needed to counter age discrimination in the transport system, including improvement in vehicles (i.e. low floor buses), subsidised taxis, appropriate pricing schemes and community transport schemes. There is a need to develop methods to evaluate developments in policy and practice.
Ahrens (2005)	Germany	Ageing and the rising number of one-person households will increase car-dependency. Suburban areas will grow stronger relative to city centres during the coming decades. The increase in the population at the age of 60+ will be stronger in suburban areas than in city centres. This will lead to the significant growth in car traffic in suburban areas. Demographic changes and further suburbanization will force the development of affordable, low-demand public transport and redesigning oversized social and transport infrastructure.
Mercado et al. (2010)	Canada	Introduction of age-based driver licensing and a renewal policy for citizens aged 80+. It will be necessary to improve the accessibility, convenience and flexibility of public transport services to meet the needs of older people.
Driscoll et al. (2018)	USA	It will be necessary to adjust the public transport system to older cohorts' needs and preferences by increasing accessibility and mobility options. To tailor policy measures, it is important to recognize areas where the population will decrease the most.
Pomoni et al. (2020)	–	For the passenger transport sector, the ageing of the population will force cities to redesign public transport systems in terms of infrastructure, planning and new innovative patterns, such as automated vehicles and shared mobility schemes.

- How will ageing and depopulation influence aggregate transport behaviour, characterized by the daily number of trips and the modal split in the investigated area?
- To what degree are results from large cities investigated in previous studies comparable with findings for the central part of Silesia Province in Poland?
- How will ageing and depopulation affect the transport system?

3. Materials and methods

3.1. Characteristics of the study area

The central part of Silesia Province was chosen for this study. Silesian Province is a highly industrialized and urbanized region in Southern Poland (the location of the area on the map of Poland is shown in Fig. 1. It generates approx. 12% of the country's GDP. The population of the province exceeds 4.5 million people, and the average population density



Fig. 1. Study area in Poland (red color – study area, blue color – Silesia Province). Source: own study. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

is approximately 368 person/km². The area chosen for the study covers 42 municipalities located in the central part of the province. This area is one of the largest urban conurbations in Central Europe. The main development core of this area is 15 cities that form a compact conurbation. The remaining smaller municipalities surround the main core, forming its functional area. In 2017, the population of the area was 2.36 million in an area of approx. 27 thousand square kilometres (the population density was approx. 872 inhabitants/km²) (Statistics Poland Database, 2023). This area is characterized by high internal and external transport accessibility. The road and rail network density indicators are among the highest in the country.

In 2017, the municipalities were served by five independent public transport organizers: KZK GOP (Municipal Transport Union of the Upper Silesian Industrial District) in Katowice, MZKP (Intermunicipal Public Transport Association) in Tarnowskie Góry, MZK (Municipal Transport Authority) in Tychy, MZDiM (Municipal Road and Bridge Administration) in Jaworzno, and Marshal Office of the Silesia Province. Currently, as a result of integration processes, the area is served by three organizers: ZTM (Metropolitan Transport Authority) in Katowice, MZUiM in Jaworzno, and Marshal Office. The public transport offer includes the following means of transport: bus, tram, trolleybus, and train. As regards the development of the system, great emphasis is placed on the integration of means of transport through the construction of a system of multimodal transport hubs. Most of the public transport offer is covered by one fare system. The transport system is also supplemented with sharing mobility solutions, such as city bike systems and scooter rentals.

Table 3
Population and its structure in Silesia Province in 2017–2021. Source: own study based on (Statistics Poland Database, 2023).

Age	2017	Share [%] in 2017	2018	2021	Share [%] in 2021	Average annual rate of change 2017–2021[%]	Change 2021/2017 [%]
total	4,548,180	100%	4,533,565	4,375,947	100%	−0.96%	−3.79%
0–4	214,021	4.7%	214,014	199,223	4.6%	−1.78%	−6.91%
5–19	640,011	14.1%	639,836	639,355	14.6%	−0.03%	−0.10%
20–44	1,620,859	35.6%	1,594,823	1,465,444	33.5%	−2.49%	−9.59%
45–64	1,256,532	27.6%	1,242,834	1,193,737	27.3%	−1.27%	−5.00%
65–79	625,235	13.7%	644,509	679,113	15.5%	2.09%	8.62%
80+	191,522	4.2%	197,549	199,075	4.5%	0.97%	3.94%

The central part of the Silesia Province, which was selected as the research area, is characterized by an integrated and co-financed public transport system. The main transport problems in this area include a growing level of individual motorization, with the falling demand for public transport. The selected area is characterized by a high level of urbanization; it is one of the largest conurbations in Central Europe. Consequently, the results of the research can be extrapolated to other cities and metropolitan areas.

Silesia Province is the second most populous province in Poland, comprising about 12.1% of the Polish population in 2021 (Statistics Poland Database, 2023). The process of ageing and depopulation is visible in this province, as the population is steadily decreased by around 1% annually in the period 2017–2021 (Table 3). A decrease in the youngest groups is also observed, while the older age group 65+ is increasing.

3.2. Methods

In the first step of our procedure, we examined the relationship between age and other age-related factors and the transport behaviours of the respondents. We used multinomial logistic regression (see Greene, 2012; Hosmer and Lemeshow, 2000) for both dependent variable although the daily number of journeys is an ordered measure. However, the relationship between the number of journeys and its potential determinants seems to be highly nonlinear, and therefore difficult to capture by a parsimonious ordered logistic regression model, which is founded on the restrictive parallel regression assumption.

The estimated multinomial logistic regression model took the following form:

$$\begin{cases} P(Y = j|x) = \frac{\sum_{i=1}^k \gamma_i^{(j)} x_{ij}}{1 + \sum_{j=1}^{m-1} \sum_{i=1}^k \gamma_i^{(j)} x_{ij}} + \xi^{(j)}, \text{ for } j = 1, 2, \dots, m - 1, \\ P(Y = m|x) = \frac{1}{1 + \sum_{j=1}^{m-1} \sum_{i=1}^k \gamma_i^{(j)} x_{ij}} + \xi^{(m)}, \end{cases} \quad (1)$$

where Y represents the multinomial variable that takes values indexed by $j = 1, 2, \dots, m$, and, without loss of generality, the outcome m is set to be the reference outcome, x_{ij} stands for regressors, $\gamma^{(j)}$ are the sets of regression coefficients, and $\xi^{(j)}$ represents error terms. The set of exogenous variables consisted of a constant, age cohort dummy variables, and the other characteristics of respondents: gender, occupation, education level, physical fitness, and possession of a driving license. Additionally, we also included the location variable representing counties of the Silesia Province. We also considered replacing the set of age cohort dummies with a cubic function for age in years which is a more parsimonious specification and may deliver slightly more reliable predictions. The results, however, did not differ much so we did not report them. The parameters were estimated using the maximum likelihood method, and the standard errors of the estimates were calculated using the heteroscedasticity-consistent estimator.

The main advantage of multinomial logistic regression is that the

predicted probabilities for the complete set of outcomes sum up to one. This is an important feature for determining projected consequences of demographic changes. However, the relative risk factors – the estimates of the multinomial logistic regression models – are not very convenient for interpretation as compared to the odds ratios produced by the simple binary logistic regression models. The latter compare the odds of choosing a specific outcome for respondents of different characteristics, while the former show to what extent the ratio of two outcome probabilities depends on the respondent characteristics. So, the relative risk factors do not explicitly show if older respondents are more likely to make a specific choice than younger ones. Instead, they inform if older respondents are more likely to prefer one outcome over another one, without indicating if they choose a specific outcome more often in general. As a consequence, when reporting the results of the first step of the procedure we show and interpret the odds ratio from the set of binary logistic.

Our sample consisted of journey characteristics of household members. Because one person can report several journeys and a household can be formed of several persons, the observations can be dependent. To account for the dependence, we also estimated the random intercept (hierarchical) version of the baseline model where intercepts were either respondent- or household-specific. However, the results did not differ from those obtained from the baseline specification, so we did not report them. They are available upon request.

In the second step of the procedure, we blended the results from the first step with the demographic projection to create a projection of the daily number of journeys and the journey structure by modes of transport for the next decades until 2050. More specifically, we used the estimated multinomial regression model to calculate the probabilities assigned to the outcomes for people with different characteristics. Then, we multiplied the probabilities by the expected population from the projection and got the projections of the transport behaviour indicators.

The population projection provides estimates of the total population and its age and gender structure¹, but it does not cover the other characteristics considered in this study that are undoubtedly related to age, such as occupation or physical fitness. We took into account the changes in these characteristics induced by ageing, by assuming that the future structure with respect to these characteristics for people from different age groups is the same as currently observed. For example, we assumed that the future fractions of pensioners among people aged 65–69 would be equal to the fraction observed in the sample, adjusted by sampling weights.

We employed the parametric bootstrap method for calculating the standard errors of our final predictions, although they do not account for the uncertainty associated with the population projection, as they are not reported. Therefore, the errors cannot be treated as a reliable assessment of total projection uncertainty. Nonetheless, it is still a valuable indicator of the uncertainty related to the estimated impact of age and the age-related factors.

3.3. Data

The survey was carried out by three independent research companies at the request of a regional authority (Association of Municipalities and Poviats of the Central Subregion of the Silesia Province) in the last quarter of 2017. During the survey, the pollsters reached 16,280 households, conducting a total of 33,933 interviews (Kostelecka et al., 2018).

The survey was preceded by an information campaign to encourage cooperation with pollsters and generate social trust. The interviewers were equipped with appropriate ID cards. The target research sample

¹ It also covers location, but we did not take it into account because of the low reliability. Instead, we summed up the projections for different locations into a single aggregate projection for the whole area.

was chosen randomly and the household addresses were drawn from an official statistical database. For each household address, three additional, spare addresses were drawn. At each address, as many household members as possible were interviewed. The work of the pollsters was constantly verified by telephone (telephone contact with respondents) and through quality control of the collected surveys (Kostelecka et al., 2018). To match the gender and age structure of the population living in the area under investigation better, the importance weights were calculated for each person.² The weights were used in all our calculations if not specified otherwise.

The interviews concerned trips of all household residents who were at least 7 years old. The household survey was conducted directly in-house (face-face interviews), using the method of one-day travel diary survey, so the questions concerned activities and travel behaviours on the day preceding the day of the survey. Respondents were asked to describe every journey they had made the day before, including: start and end times, means of transport, destination, distance, travel time, walking distance and time to public transport stop, waiting time etc (Kostelecka et al., 2018). One-day travel diary survey methods are widely accepted and used in travel behaviour research and practice of travel modelling (Sammer et al., 2018; Stopher et al., 2007).

We restricted the sample to the households living in the central subregion of the province, which consists of >15 cities with a population exceeding 50,000 inhabitants (Statistics Poland Database, 2023). The respondents with any missing data used in our study were excluded. The structure of our final sample is characterized in Table 4. It covers 23,975 persons from >11,000 households. Although our sample covers a smaller area than the original study, and the inhabitants in the two areas have slightly different demographic characteristics, we retained the original weights. Applying the weights allowed us to match the demographic structure of the population at the end of 2018 quite well, with one exception: the share of respondents of age 65–79 in our sample (16.94%) is higher than in the population (12.20%), and the remaining age groups are slightly underrepresented, out of which the bias for the group 80+ is the highest (3.38% in the sample and 4.97% in the population). Nonetheless, we do not think that the sampling bias affects the results of our study considerably as discussed at the end of Section 4.1. The other characteristics of the respondents considered in our study include: education level (measured by the ISCED scale), occupation, possessing driving license, physical fitness, and location. Unfortunately, for these variables no reliable data for the whole population considered in our study exists.

Our sample also includes children, because we see ageing not only as the effect of rising life expectancy, but also of a decrease in fertility. To be able to study the consequences of the latter, we have to analyse the travel behaviours of youth.

We considered two groups of variables describing transport behaviours of the respondents: daily number of journeys and transport mode usage. These variables are characterized in Table 5. Those and all subsequent results were weighted using the weights discussed above. >60% of respondents made two journeys a day. About 17% made no journey at all. >8% travelled three or four times. A tiny fraction realized just one or more than four journeys. In total, the respondents made over 47,000 journeys, of which almost two-third were pedestrian and car (as a driver) travels. About 19% of travels were made by public transport, and 9% as passengers in a car.

² The following formula was used for calculating the importance weights:

$$w_{a,s} = \frac{N_{a,s}^{pop} N^{sam}}{N_{a,s}^{sam} N^{pop}}$$

where $w_{a,s}$ denotes the importance weigh for a person of age a and gender s , $N_{a,s}^{pop}$ and $N_{a,s}^{sam}$ represent the number of people from a given cohort in the population and the sample, respectively, and N^{pop} and N^{sam} are the total number of people in the population and the sample.

Table 4
Characteristics of the respondents. Source: own study.

	Number of respondents	Fraction [%]	Fraction after weighting [%]	Fraction in population [%]
Gender				
Women	12,853	53.61	52.26	51.96
Men	11,122	46.39	47.74	48.04
Age				
7–12	1507	6.29	5.66	6.58
13–17	1023	4.27	4.25	4.58
18–24	1637	6.83	7.21	7.35
25–44	7388	30.82	32.65	33.58
45–64	6489	27.07	29.92	30.73
65–79	4865	20.29	16.94	12.20
80+	1066	4.45	3.38	4.97
Education level (ISCED)				
lower secondary or lower (0–2)	4746	19.80	18.53	
upper secondary or post-secondary vocational (3.4–4.4)	7612	31.75	31.58	
upper secondary or post-secondary general (3.5–4.5)	7730	32.24	33.03	
tertiary or higher (5–8)	3887	16.21	16.87	
Occupation				
Pupil	3179	13.26	12.73	
Student	433	1.81	2.02	
Working outside home	9788	40.83	43.85	
Working at home	646	2.69	3.03	
Unemployed	1431	5.97	5.87	
Pensioner	7744	32.30	29.11	
Other	754	3.14	3.38	
Driving license				
Yes	12,155	50.70	52.21	
No	11,820	49.30	47.79	
Physical fitness				
Full	21,588	90.04	91.14	
Slight restriction	1505	6.28	5.56	
Moderate restriction	656	2.74	2.40	
Severe restriction	130	0.54	0.49	
Only with an assistant	96	0.40	0.41	

The population projections for counties of Silesia Province are prepared by the Polish central statistical office in 2014 (Statistics Poland, 2014). Similarly to many other industrialized regions in developing countries, Silesia Province is going to experience the following three demographic processes: decreasing fertility, increasing life expectancy, and suburbanization. The consequences of the processes are considerable decline of the total population and ageing, which means an increase in the fraction of older inhabitants.

The predicted population decline and the changes in its age structure in the period 2018–2050 are depicted in Fig. 2. The total population is expected to drop from 2.5 million in 2018 to 1.9 million in 2050. At the same time, the share of population 80+ will surge from 5% to 12%, and the share of population aged 65–79 will double.

4. Results

4.1. Number of journeys

Table 6 contains the odds ratios for the determinants of the daily number of journeys. The impact of respondent age on the probability of making certain numbers of journeys is reported in the first part of the Table, and the corresponding age profiles for the odds ratio are depicted

Table 5
The structure of the sample with respect to the daily number of journeys and the transport modes used. Source: own study.

	Daily number of journeys					
	No journey	One journey	Two journeys	Three journeys	Four journeys	Five and more journeys
Total	16.94	1.56	62.70	8.87	8.23	1.71
7–12	11.14	0.18	72.26	6.14	9.81	0.47
13–17	9.74	0.94	71.81	5.36	11.78	0.37
18–24	13.62	2.04	63.96	8.52	11.22	0.63
25–44	11.70	1.99	62.86	10.26	10.07	3.13
45–64	15.99	1.88	63.99	9.64	7.06	1.44
65–79	29.01	0.76	56.53	7.63	5.17	0.91
80+	41.18	0.63	50.49	4.53	2.80	0.37
	Modes of transport					
	On foot	Car as driver	Car as passenger	Public transport	Bicycle	Other
Total	32.74	31.89	9.42	18.95	1.62	5.37
7–12	68.29	0.00	19.93	6.60	0.39	4.78
13–17	59.13	0.00	11.17	24.44	0.59	4.67
18–24	27.60	17.98	7.91	37.71	1.19	7.62
25–44	25.43	45.44	6.79	15.91	1.29	5.15
45–64	26.83	37.67	8.84	18.66	2.20	5.79
65–79	41.01	19.24	13.23	19.60	2.48	4.43
80+	47.28	11.32	9.43	26.68	0.43	4.86

in Fig. 2. The clear nonlinear relationship is observed for no journey and five and more journeys. In the first case, the relationship is U-shaped: the probability of making no journey is the lowest for respondents aged 25–74, and significantly higher for children and respondents aged 75+. An inverse relationship is observed for five and more journeys. There is a clear peak in the odds ratio around the cohort 35–39 whereas the younger and the older cohorts are characterized by considerably lower odds. To some extent a similar picture is observed in the case of three journeys, although the peak there is much flatter. For one, two, and four journeys, the differences between cohorts are definitely less pronounced and only a few of them are characterized by statistically significant higher or lower odds. To sum up, respondents aged 25–45 are characterized by the highest mobility. A lower journey intensity is observed among younger and older age groups, whereas the oldest respondents, aged 75+, travel the least.

As far as the occupations are concerned, the reference group consists of respondents working outside home. Pensioners generally travel less often than the reference group. Mobility among students is also generally lower than the reference group. More often they make no journeys, and are less likely to make four or more trips per day. Pupils are less likely to make no journey, but as far as the other numbers of journeys are concerned, the differences are not statistically significant. Finally, respondents working at home and of other occupations seem to be highly diversified groups as far as the number of journeys is concerned having significantly higher odds for zero as well as five or more journeys.

The results for the physical fitness level have confirmed the expected tendency: more physically-restricted respondents are less likely to travel.

It should be noted that the sampling bias, in particular the overrepresentation of the 65–79 and the underrepresentation of the oldest cohort, discussed in Section 3.2 is likely to have a limited impact of these results. Because we explicitly controlled for the age and other age-related factors in the regressions the bias slightly affects the shapes of the age profiles that are overly sensitive to the observations for the 65–79 cohort and undermine the impact of the 80+ cohort.

4.2. Modal split

Table 7 contains the results for the transport modes used for travelling. The corresponding age profiles of the odds ratios are presented in

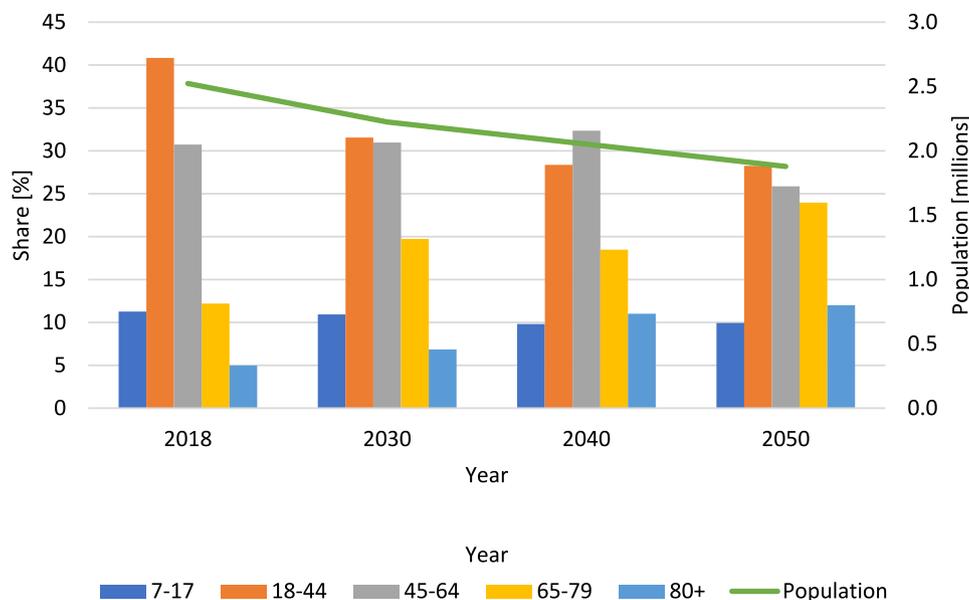


Fig. 2. The current and projected population and its structure in the area under investigation. Source: own study.

Fig. 4. The first part of the table documents a significant nonlinearity of the relationship between the modes of transport and age, which is also shown in Fig. 3. The odds ratio for travelling on foot and by car as a passenger is definitely the highest for children. For the older cohorts, the differences are small, although there are other minor peaks in the odds for the cohort 30–44 in the case of travelling on foot and the cohort 60–79 for travelling by car as a passenger. The odds ratio for travelling by car as a driver, as well as for bicycle usage, exhibit clear reverse U shapes, with the maximum located between 30 and 59 years of age in the case of cars, and about 55–74 years of age for bicycles. The frequency of public transport usage is the lowest for children and the highest for young adults (18–29) and the 75+ cohort. However, the low odds for children may be a spurious result, as the estimates also show that pupils tend to prefer public transport compared with the reference group of those working outside home.

4.3. The projections of aggregate transport behaviour

Table 8 contains the projected daily number of journeys and its structure by mode of transport. The results for 2018, in which both, the sample- and model-based estimates, are reported, show that the model is able to match the structure of journeys very well. The differences do not exceed a few base points. The most significant change in the structure of daily journeys by number is the rise in people who do not make any journeys from almost 17% in 2018 to >19% in 2050. On average, the share of people making one or more journeys drops slightly. As a result, the average daily number of journeys is expected to decrease from 1.95 to 1.88, that is, approximately by 3.6%. However, the significant decrease in total population will cause a huge drop in the total number of daily journeys, which, according to our projections, will decline from almost 5 million in 2018 to 3.5 million in 2050, i.e. by 30%.

The expected structure of journeys by mode of transport is shown in Table 9. The biggest change should be associated with using a car as driver, whose share is expected to drop from 32% in 2018 to 26.7% in 2050. However, to some extent this drop may result from underestimation of the fraction of the car-as-driver journeys by our projection as shown in the results for 2018. At the same time, we should also expect increases in travelling on foot and journeys by car as a passenger. The share of bicycle journeys will almost double.

It should be noted that the bootstrapped standard errors reported in brackets are relatively low, which means that the estimation errors are

very unlikely to affect considerably the qualitative conclusions from our projections.

As we mentioned in the previous section, there are no alternative population projections available for the studied region, so we are unable to run robustness checks in this regard. Moreover, both at the national and regional levels, studies of transport behaviour are not conducted periodically on a large scale according to one coherent methodology that would enable the comparability of the results. Such studies are usually conducted during the development of a transport model for the needs of important strategic documents and planning. However, some intuitive conclusions can be drawn from the various variants of the UN population projections for Poland. Most importantly, in the optimistic variant of the projection, the drop in the country-level population is about half of what is expected in the medium variant, and the age structure of the population changes only a little. Assuming that this relationship also holds for the area under investigation, the drop due to depopulation is still considerably higher as compared with the effects of ageing. On the other hand, in the pessimistic variant of the projects, the impact of depopulation is even considerably stronger than our estimates show.

5. Discussion and conclusions

In terms of the level of mobility measured by the daily number of trips, the results of this study are in line with previous literature (Hensher, 2007; O'Fallon and Sullivan, 2009; Buehler and Nobis, 2010; Liu et al., 2017; Hebel and Wolek, 2021). Our results indicate that the highest mobility is characteristic for people aged 30–50. Taking into account the reference age (35 years old), we can conclude that for the area studied, the daily number of journeys decreases significantly after the age of 50. When analysing the results from the point of view of professional activity/occupation, it can be observed that pensioners generally travel less often than other groups. Retirement age was also recognized as a major factor affecting travel behaviours in several other studies. Moreover, the results have also confirmed the expected tendency that age-related impairments significantly influence mobility, as more physically restricted respondents are less likely to travel.

The choice of travel mode is influenced by many factors, e.g. traffic conditions in a particular area, distance between the place of residence and the destination, and various personal characteristics, e.g. gender, age, standard of living and lifestyle, access to a private car, as well as the nature of the need itself, or even the value attributed to a specific travel

Table 6
Determinants of the daily number of journeys – odds ratios from the logit models. Source: own study.

Regressors	Dependent variable – daily number of journeys					
	No journey	One journey	Two journeys	Three journeys	Four journeys	Five and more journeys
Age group [35–39]						
7–12	1.955** (2.484)	0.161** (–2.107)	1.213 (1.092)	0.585* (–1.811)	0.847 (–0.679)	0.515 (–0.731)
13–17	1.623* (1.680)	0.924 (–0.106)	1.206 (1.008)	0.478** (–2.373)	1.067 (0.263)	0.400 (–0.981)
18–24	1.439** (2.149)	1.039 (0.089)	0.983 (–0.148)	0.814 (–1.110)	1.192 (1.086)	0.239*** (–3.187)
25–29	0.862 (–1.044)	0.995 (–0.019)	1.186* (1.915)	0.932 (–0.499)	1.058 (0.406)	0.552** (–2.575)
30–34	1.096 (0.731)	1.177 (0.589)	1.028 (0.331)	0.752** (–2.039)	1.317** (2.069)	0.673* (–1.818)
40–44	0.764** (–2.001)	0.732 (–1.128)	1.226** (2.369)	0.965 (–0.272)	1.059 (0.409)	0.702 (–1.437)
45–49	1.099 (0.714)	0.926 (–0.267)	1.371*** (3.691)	0.745** (–2.182)	0.649*** (–3.008)	0.542** (–2.088)
50–54	0.801 (–1.571)	1.857** (2.234)	1.281*** (2.648)	0.981 (–0.132)	0.886 (–0.744)	0.201*** (–4.732)
55–59	1.020 (0.153)	0.822 (–0.619)	1.269*** (2.630)	0.912 (–0.632)	0.854 (–0.999)	0.251*** (–4.678)
60–64	1.104 (0.737)	0.970 (–0.106)	1.127 (1.224)	0.927 (–0.466)	1.098 (0.504)	0.332*** (–3.097)
65–69	1.253 (1.610)	1.127 (0.268)	1.136 (1.195)	0.644** (–2.239)	1.177 (0.729)	0.357*** (–2.893)
70–74	1.075 (0.479)	0.321** (–2.132)	1.308** (2.319)	0.938 (–0.318)	0.648* (–1.690)	0.226*** (–3.622)
75–79	1.782*** (3.827)	0.835 (–0.396)	0.890 (–0.969)	0.707* (–1.658)	0.872 (–0.503)	0.050*** (–4.961)
80–	1.629*** (3.168)	0.636 (–0.903)	1.086 (0.648)	0.445*** (–3.302)	0.609 (–1.458)	0.123** (–2.421)
Occupation [Working outside home]						
Pensioner	3.151*** (11.560)	0.359*** (–3.639)	0.665*** (–5.230)	0.907 (–0.657)	0.581*** (–3.068)	1.593 (1.642)
Student	1.478* (1.803)	1.191 (0.319)	0.994 (–0.040)	0.925 (–0.344)	0.633* (–1.942)	0.787 (–0.339)
Pupil	0.523** (–2.565)	0.673 (–0.629)	1.234 (1.259)	0.905 (–0.354)	1.468 (1.525)	0.387 (–1.102)
Working at home	3.452*** (9.568)	0.789 (–0.814)	0.512*** (–6.391)	1.049 (0.274)	0.895 (–0.589)	2.370*** (3.648)
Unemployed	2.904*** (10.325)	0.404** (–2.197)	0.559*** (–7.634)	0.849 (–1.193)	0.995 (–0.044)	3.653*** (6.761)
Other	3.649*** (10.299)	0.311** (–2.132)	0.473*** (–7.614)	0.834 (–0.980)	0.781 (–1.311)	5.175*** (7.306)
Physical fitness [Full]						
Slight restriction	1.276*** (2.630)	1.523 (1.028)	0.829** (–2.388)	1.072 (0.534)	0.966 (–0.213)	0.913 (–0.256)
Moderate restriction	3.060*** (10.066)	1.405 (0.475)	0.459*** (–7.326)	0.580** (–2.041)	0.651 (–1.411)	0.104** (–2.181)
Severe restriction	6.716*** (7.107)	1.520 (0.474)	0.217*** (–5.583)	0.698 (–0.558)	0.152* (–1.867)	
Only with an assistant	3.571*** (4.384)	4.092 (1.348)	0.440*** (–2.959)	0.133*** (–2.581)	0.576 (–0.881)	
Gender [Women]						
Men	0.972 (–0.548)	1.339* (1.897)	1.295*** (6.808)	0.671*** (–6.037)	0.822*** (–3.068)	0.513*** (–4.505)
Education level [Tertiary or higher]						
Lower sec. or lower	0.927 (–0.681)	1.044 (0.104)	1.011 (0.123)	0.990 (–0.064)	1.020 (0.104)	1.070 (0.187)
Upper sec. Vocational	0.794*** (–2.719)	1.614** (2.220)	1.182*** (2.813)	0.875 (–1.402)	0.906 (–0.953)	0.844 (–0.974)
Upper sec. general	0.702*** (–4.430)	1.548** (2.108)	1.219*** (3.599)	0.836** (–2.097)	1.125 (1.278)	0.889 (–0.687)
Driving license [No]						
Yes	0.896* (–1.820)	1.214 (1.091)	0.875*** (–2.927)	1.172** (2.095)	1.256*** (2.663)	1.456** (2.257)
Constant	0.094***	0.009***	1.369***	0.209***	0.122***	0.070***

(continued on next page)

Table 6 (continued)

Regressors	Dependent variable – daily number of journeys					
	No journey	One journey	Two journeys	Three journeys	Four journeys	Five and more journeys
Observations	(-17.632)	(-14.708)	(3.502)	(-11.332)	(-13.493)	(-8.958)
Pseudo-R ²	23,975	23,975	23,975	23,975	23,975	23,611
	0.164	0.101	0.0585	0.0722	0.0708	0.177

Note: The table contains the odds ratios from the estimated binary logit models. In brackets, base values of the nominal variables are shown. For brevity, the estimates of the location coefficients are not reported. Robust z-statistics are reported in parentheses. The statistically significant estimates are bolded and marked with asterisks (***) $p < 0.01$, ** $p < 0.05$, * $p < 0.1$).

Note: The reference age is 35–39 years. The vertical lines represent 95% confidence intervals for the odds ratio estimates.

activity (Litman, 2017a; Ye et al., 2007). Moreover, the mode choice is also heavily influenced by habits (Redman et al., 2013; Verplanken et al., 1998). The research results show that in comparison to the reference age (35), the probability of choosing to drive a car significantly decreases over the age of 50, and the probability of choosing public transport significantly increases over the age of 70. Moreover, it can be seen that pensioners are more likely than other groups to travel on foot and by car as a passenger. On the other hand, they drive cars and use public transport less willingly. These results are also in line with other, previous studies, showing that age-related impairments influence the capability to drive (Box et al., 2010; Raitanen et al., 2003). According to Ryan et al., 2019, poorer health reduces the scope of an individual's modal choice. Furthermore, physically restricted respondents are less likely to use public transport and bicycles, which is in line with expectations.

Moreover, the study results show that pensioners are more likely to travel by car as passengers, and less likely to use public transport, which is mainly due to the poor technical condition of public transport and to convenience. On the other hand, research by Kizony et al., 2020 has shown that the unwillingness to use public transport is also correlated with younger age and economic status. Taking into account convenience and the requirements connected with passengers' age, the car seems to be the perfect transport mode for elderly people. Moreover, it should be noted that ageing leads to greater car-dependency. Today's pensioners represent a generation who are in the habit of using a car, or even see using the car as a right (Rosenbloom, 2001; Rees and Lyth, 2004). Habitual transport behaviours are inert, unconscious and not reasonable as they involve little information processing, and are a challenge to sustainable transport policies (Verplanken et al., 1998; Eriksson et al., 2008).

Another factor that should be taken into consideration in this context is the development of autonomous vehicle technologies (AV). The ongoing automation, in particular of passenger cars, is a technology that may enable older adults to continue driving when age-related physiological changes occur (Pettigrew et al., 2019; Yang and Coughlin, 2014), which will additionally increase the dependence on individual car transport in this age group. However, the use of autonomous vehicles in many cities facing the problem of a lack of drivers seems to be a remedy for the future (Pomoni et al., 2020; Christidis et al., 2014). For the passenger transport sector, especially public transport in many cities in Poland and Eastern Europe countries, the ageing workforce is making it necessary for public transport organizers to limit public transport services. In the future, this situation may force cities to redesign their transport systems.

Moreover, the results of our projection have made another contribution to the current state of knowledge in this field. Our projections have proven that the aggregate consequences of ageing are rather limited in the area studied. Depopulation plays a considerably more important role in the total number of journeys by transport modes compared to ageing. The former would result in a drop in the total number of journeys by 30%, whereas the latter – by just 3%. Of course, the heterogeneity of the ageing processes across cities should generate proportional differences in transport behaviour dynamics.

As the current generation of older people is more active than

previous generations of comparable age, public transport will play a key role in maintaining their active lifestyle, even if they are unable to drive. For this reason, public transport is important for the quality of life of older people, their sense of freedom and independence. Therefore, preventing mobility exclusion of this social group is one of the important goals of social and transport policy. Our research has clearly shown changes in the mobility patterns of older people compared to younger people. Due to health limitations, some older people will be inclined to use public transport. It is very likely that in the EU it is the public transport system that will be most affected by the ageing of the population. Main EU transport policy documents indicate the necessity of developing sustainable transport systems. These systems should be based on the principle of inclusiveness, and made available to all user groups, including the elderly.

5.1. Implications for transport policy

Ageing and depopulation will force the rethinking and redesigning of transport systems, as well as the integration of all policy measures, including transport and land use policy, the environment, social objectives and economics. Primarily, there is a need to focus on increasing the efficiency of large infrastructure investments, as well as verification of their costs and benefits, as such projects may prove to be oversized in terms of estimated demand and very expensive to maintain (Ahrens, 2005). This means more focus on transport integration and integrated transport planning.

According to the latest research, a constantly growing challenge for transport policy remains the traffic generated by suburbs. Ageing and depopulation will contribute to this problem. One relatively new urban concept is that of the 15-min city, which assumes the availability of many basic social services for every inhabitant (e.g. work, shopping, education, healthcare) at a walking or cycling distance of 15 min. This is based on sustainable mobility and a maximum reduction in transport demand for longer distances requiring the involvement of e.g. a passenger car (Abdelfattah et al., 2022; Caselli et al., 2022). This approach is difficult to implement, while the idea of planning public functions in a more distributed and available form for residents is a response to the ageing process of society. Apart from sustainable planning, the basis for conducting an effective transport policy that takes into account the needs of the elderly is the identification of their expectations. As part of the GOAL project (Growing Older and Staying Mobile), four basic groups of needs were identified: affordability, availability, accessibility and acceptability (Shresta et al., 2017).

Moreover, according to Ahrens (2005), more and more focus will be given to soft and cheap measures such as taxation and pricing, regulations and restrictions, management, information and education, and cooperation. These measures may include the introduction of age-based driver licensing and a renewal policy for older citizens (Mercado et al., 2010), restrictions on car use and congestion and parking charges, and the allocation of more space for public transport and cycling (Metz, 2012).

Based on the results of our research and the literature review, we have prepared a summary of the impact of the demographic changes on the functioning of public transport (see Table 10). The authorities

Table 7
Determinants of the modes of transport – odds ratio from the logit models. Source: own study.

Regressors	Dependent variable – mode of transport for a journey					
	On foot	Car as driver	Car as passenger	Public transport	Bicycle	Other
Age group [35–39]						
7–12	6.448*** (9.050)		6.130*** (5.895)	0.080*** (–11.363)	0.074** (–2.234)	0.607 (–1.345)
13–17	4.021*** (6.574)		2.744*** (3.058)	0.377*** (–4.824)	0.064*** (–2.632)	0.827 (–0.485)
18–24	1.108 (0.684)	0.536*** (–4.352)	1.187 (0.802)	1.649*** (3.743)	0.360 (–1.351)	1.159 (0.542)
25–29	0.982 (–0.156)	0.691*** (–3.670)	1.299 (1.560)	1.424*** (3.101)	1.134 (0.287)	1.616** (2.441)
30–34	1.309** (2.560)	0.945 (–0.598)	0.670** (–2.254)	0.948 (–0.448)	0.886 (–0.328)	1.027 (0.129)
40–44	1.235* (1.921)	0.918 (–0.896)	0.766 (–1.500)	1.190 (1.530)	1.064 (0.174)	0.909 (–0.470)
45–49	0.921 (–0.761)	1.061 (0.626)	0.750 (–1.625)	1.078 (0.655)	1.237 (0.585)	1.149 (0.717)
50–54	0.863 (–1.261)	1.035 (0.314)	0.903 (–0.556)	1.235* (1.659)	1.265 (0.578)	1.381 (1.549)
55–59	0.835 (–1.590)	0.908 (–0.898)	0.982 (–0.100)	1.087 (0.686)	2.168** (2.262)	1.695*** (2.755)
60–64	0.837 (–1.427)	0.806* (–1.793)	1.179 (0.958)	1.389** (2.449)	1.666 (1.508)	1.033 (0.126)
65–69	0.859 (–1.196)	0.822 (–1.486)	1.104 (0.526)	1.196 (1.206)	2.353** (2.290)	1.016 (0.062)
70–74	1.024 (0.172)	0.769* (–1.657)	1.292 (1.259)	1.006 (0.037)	1.827 (1.519)	1.018 (0.061)
75–79	0.893 (–0.744)	0.607*** (–2.896)	1.122 (0.528)	1.409* (1.952)	0.979 (–0.048)	0.588* (–1.695)
80–	1.018 (0.110)	0.552*** (–2.628)	0.653* (–1.777)	1.570** (2.311)	0.424 (–1.471)	1.236 (0.664)
Occupation [Working outside home]						
Pensioner	2.599*** (10.262)	0.431*** (–8.600)	1.091 (0.719)	0.585*** (–4.812)	0.837 (–0.730)	0.748 (–1.560)
Student	0.795 (–1.177)	0.774 (–0.730)	0.506** (–2.368)	1.682*** (2.807)	1.918 (0.604)	1.135 (0.375)
Pupil	0.666* (–1.786)	0.433*** (–4.436)	0.729 (–1.229)	2.492*** (5.610)	2.229 (1.126)	1.680* (1.660)
Working at home	1.988*** (5.041)	0.680*** (–3.175)	0.487** (–2.571)	0.403*** (–4.319)	1.650 (1.038)	1.245 (0.893)
Unemployed	3.459*** (14.043)	0.431*** (–8.600)	1.091 (0.719)	0.582*** (–4.915)	1.533* (1.657)	0.454*** (–3.824)
Other	2.578*** (7.767)	0.774 (–0.730)	0.506** (–2.368)	0.459*** (–5.140)	0.426 (–1.568)	1.035 (0.180)
Physical fitness [Full]						
Slight restriction	1.128 (1.293)	0.913 (–0.692)	1.084 (0.587)	0.856 (–1.365)	0.425** (–2.058)	0.909 (–0.417)
Moderate restriction	1.128 (0.803)	0.634* (–1.911)	0.760 (–1.269)	0.619*** (–2.624)	0.290* (–1.949)	2.022* (1.844)
Severe restriction	0.514 (–1.562)	0.101*** (–2.707)	1.416 (0.724)	0.398* (–1.930)		4.515** (2.080)
Only with an assistant	0.969 (–0.076)	1.070 (0.140)	0.583 (–1.028)	0.260** (–2.415)		6.537*** (2.642)
Gender [Women]						
Men	0.748*** (–6.210)	2.020*** (13.901)	0.633*** (–6.603)	0.739*** (–5.818)	2.919*** (6.037)	1.231** (2.169)
Education level [Tertiary or higher]						
Lower sec. or lower	1.557*** (3.912)	0.651** (–2.287)	0.892 (–0.690)	1.019 (0.150)	1.154 (0.352)	0.790 (–0.999)
Upper sec. vocational	1.269*** (3.069)	0.713*** (–4.936)	1.297** (2.091)	1.079 (0.931)	1.160 (0.521)	1.180 (1.042)
Upper sec. general	1.136* (1.721)	0.875** (–2.200)	1.318** (2.367)	1.069 (0.867)	1.163 (0.537)	1.142 (0.854)
Driving license [No]						
Yes	0.467*** (–13.971)	34.149*** (31.076)	0.709*** (–3.994)	0.243*** (–22.867)	0.344*** (–5.323)	0.468*** (–6.383)
Constant	0.356***	0.032***	0.074***	0.877	0.012***	0.038***

(continued on next page)

Table 7 (continued)

Regressors	Dependent variable – mode of transport for a journey					
	On foot	Car as driver	Car as passenger	Public transport	Bicycle	Other
Observations	(-9.154)	(-22.963)	(-14.694)	(-1.062)	(-8.904)	(-15.075)
Pseudo-R ²	19,867	21,445	23,975	19,867	19,784	19,867
	0.141	0.335	0.0653	0.134	0.109	0.173

Note: The table contains the odds ratios from the estimated binary logit models. In brackets, base values of the nominal variables are shown. For brevity, the estimates of the location coefficients are not reported. Robust z-statistics are reported in parentheses. The statistically significant estimates are bolded and marked with asterisks (***) $p < 0.01$, ** $p < 0.05$, * $p < 0.1$).

Turning to the impact of age-related occupations on the transport mode choice, it can be noticed that pensioners more often travel on foot, and are more likely to travel by car as passengers, than the respondents working outside home. Instead, they use cars as drivers and public transport less willingly. Pupils and students generally prefer public transport, and are less likely to travel by car and on foot.

Physically restricted respondents are considerably less likely to use public transport and bicycles. They usually prefer alternative transport modes and cars as passengers.

Note: The reference age is 35–39 years. The vertical lines represent 95% confidence intervals for the odds estimates.

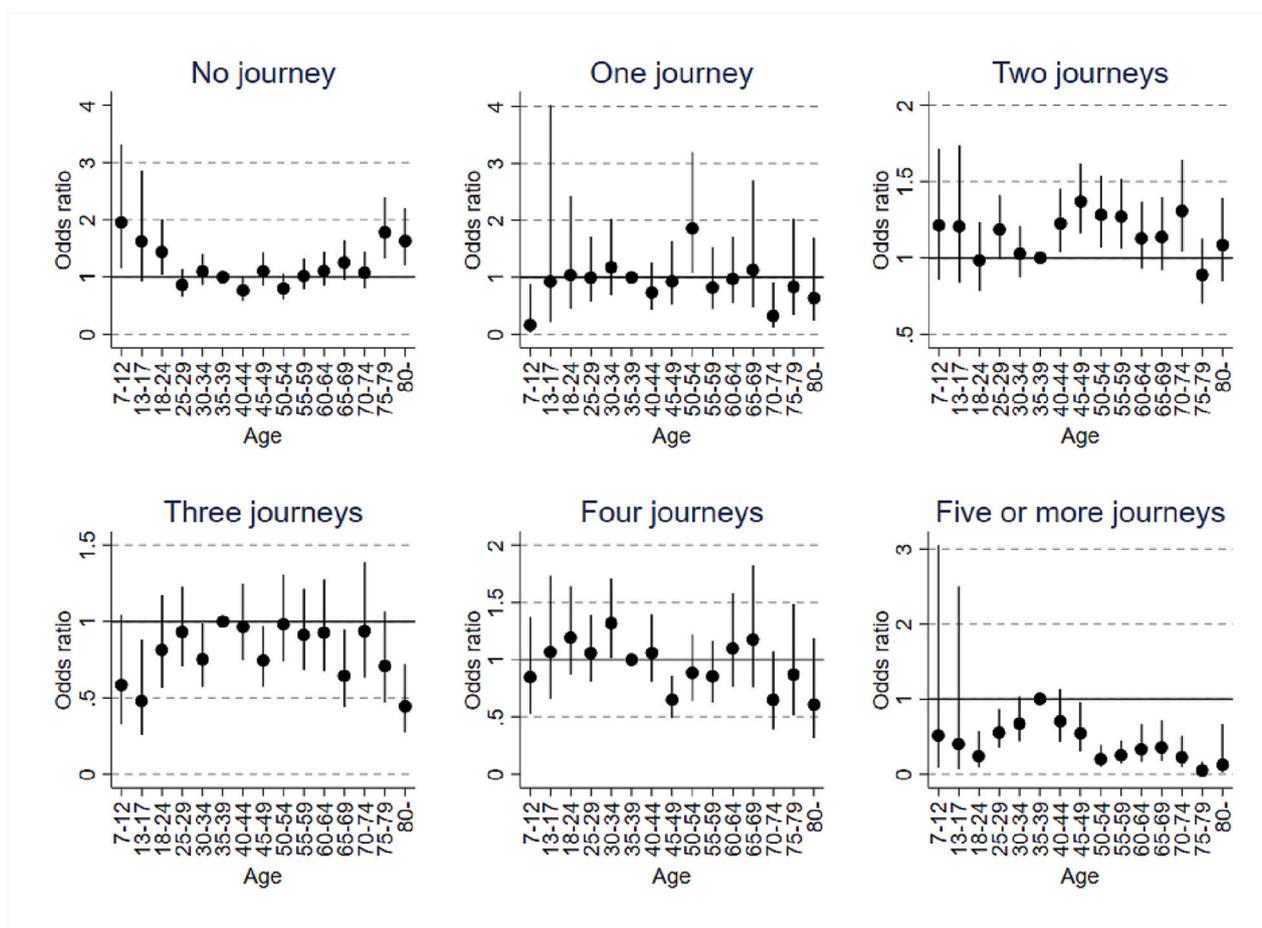


Fig. 3. Determinants of the daily number of journeys – age profiles for the odds ratios. Source: own study.

responsible for implementing transport policy should place more emphasis in their actions on the adaptation of public transport to changing needs. In particular, ageing will require an increase in public transport funding, as well as reorganization. There is a risk that public transport, especially in less prosperous countries (in particular in Central and Eastern Europe), may not live up to new expectations.

Adapting the public transport system to the demographic changes will require organisational and financial outlays. The change in the demand structure will reduce the number of passengers paying full fares, while the number of people benefiting from tariff reductions will increase. In the group of older people, there may also be increased expectations in terms of increasing discounts or the introduction of free public transport (Webb et al., 2016). A decrease in revenues will make it

necessary to involve the public sector in financing public transport more, and this may result in the necessity to limit public transport services (Šťastná and Vaishar, 2017).

A similar process may apply to other areas of life and the economy, as decreasing demand will favor decisions to limit the network of commercial, service and administrative points in areas with a strong decline in population (McArthur et al., 2014). In the case of larger cities, the depopulation process may also be noticeable and additionally intensified by the phenomenon of suburbanization.

Parallel to the decline in ticket revenues, there will be an increase in operating and investment costs. The transport needs of the elderly are more difficult to predict than in the case of professionally active people, who usually move on fixed routes: home - work - home. The limitation of

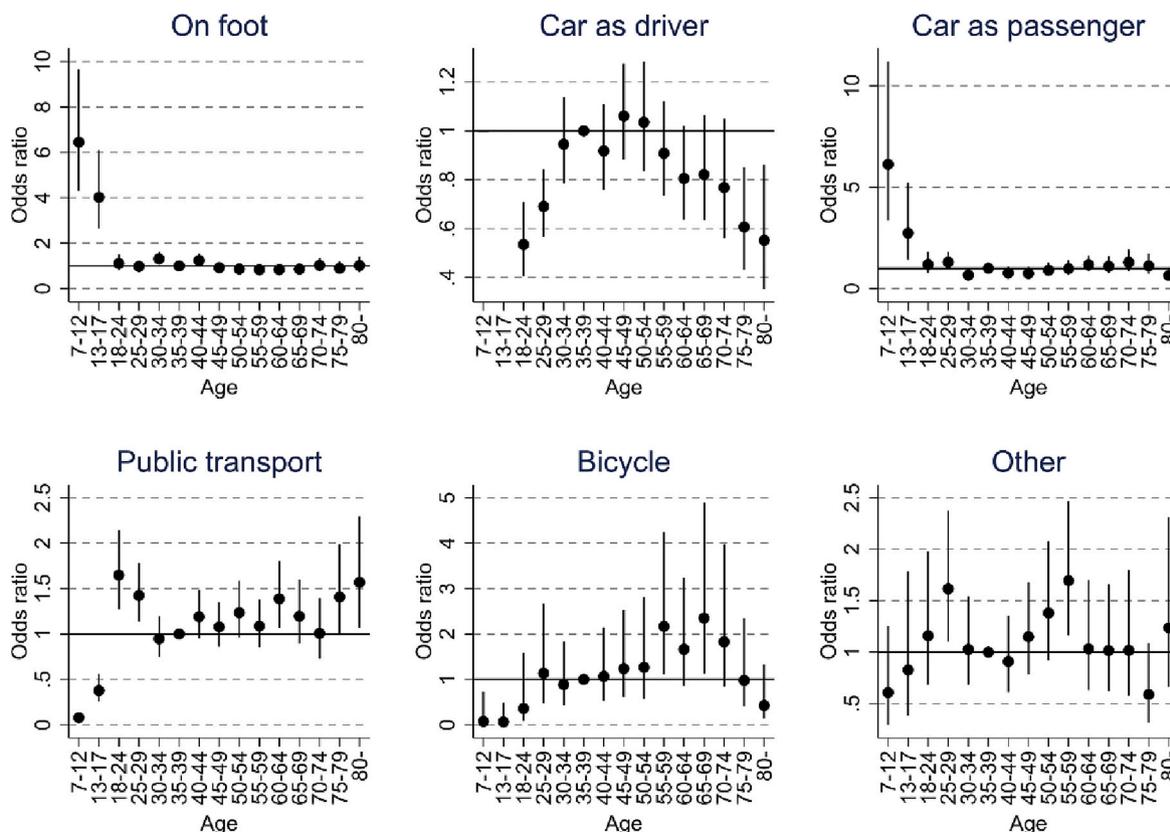


Fig. 4. Determinants of the mode of transport – age profiles for the odds ratios. Source: own study.

Table 8

The current and projected daily number of journeys. Source: own study.

	Year			
	2018	2030	2040	2050
No journey	16.94 (16.82)	17.12 [0.31]	18.25 [0.34]	19.16 [0.36]
One journey	1.56 (1.59)	1.50 [0.14]	1.46 [0.15]	1.34 [0.14]
Two journeys	62.70 (62.78)	63.63 [0.41]	63.12 [0.44]	62.62 [0.45]
Three journeys	8.87 (8.87)	8.16 [0.24]	7.96 [0.25]	7.82 [0.24]
Four journeys	8.23 (8.24)	7.39 [0.23]	7.17 [0.23]	6.97 [0.23]
Five and more journeys	1.71 (1.70)	2.20 [0.09]	2.05 [0.09]	2.09 [0.09]
Average	1.95 (1.95)	1.94 [0.01]	1.90 [0.01]	1.88 [0.01]
Population [millions]	2.52	2.22	2.05	1.88
Total daily number of journeys [millions]	4.92 (4.92)	4.31 [0.02]	3.91 [0.02]	3.54 [0.02]

Note: For 2018, the numbers show the sample-based estimates whereas in parentheses the model-based projections are reported. For the remaining years, the numbers are the model-based projections. In brackets, bootstrapped standard errors based on 1000 draws are reported (they do not account for uncertainty related to the population projection). The average daily number of journeys is calculated assuming that respondents declaring five or more journeys make five journeys.

economic activity related to ageing will increase the need for mobility between peak times. In many cities, including in the areas studied, the frequency of using public transport in the period between transport peak times is significantly lower than in peak hours. A consequence of the pressure to launch additional services will increase the operating costs of public transport organizers. In addition, it may be expected that

Table 9

The current and predicted structure of journeys by mode of transport. Source: own study.

	Year			
	2018	2030	2040	2050
On foot	32.74 (33.58)	33.34 [0.32]	33.96 [0.35]	34.99 [0.37]
Car as driver	31.89 (29.39)	28.64 [0.24]	27.57 [0.26]	26.51 [0.26]
Car as passenger	9.42 (9.79)	10.08 [0.20]	10.28 [0.22]	10.71 [0.24]
Public transport	18.95 (19.53)	18.28 [0.24]	18.37 [0.26]	18.04 [0.27]
Bicycle	1.62 (1.76)	2.77 [0.17]	2.87 [0.18]	2.94 [0.19]
Other	5.37 (5.94)	6.89 [0.18]	6.94 [0.20]	6.81 [0.21]

Note: For 2018, the numbers show the sample-based estimates whereas in parentheses the model-based projections are reported. For the remaining years, the numbers are the model-based projections. In brackets, bootstrapped standard errors based on 1000 draws are reported (they do not account for uncertainty related to the population projection).

journeys will be implemented using the “on-demand” (DRT - demand responsive transport) system, which, at least in the initial phase of the project implementation, may also increase the costs. The expectations regarding DRT system functionalities may be very complex, and will increase together with the growth of the number of elderly people accustomed to using smartphones and the Internet (Jittrapirom et al., 2019).

As a consequence of the ageing population, greater attention of public transport organizers and road authorities will have to be focused on the availability of public transport infrastructure. Not only is it necessary to provide the appropriate level of equipment at public

transport stops, but also safe, well-marked and illuminated access to them. The requirements of older people also include the availability of convenient means of transport, in particular with a low floor and a comfortable place inside the vehicle. These expectations will affect the increase in investment outlays in the field of infrastructure and means of transport, especially as low floors in trams and convenient access to passenger trains are not yet a fully common standard in Poland and other Central European countries.

The decrease in the number of births will lead in the long run to changes in educational institutions, in some cases to school closures (Haartsen and van Wissen, 2012). The problem will be particularly important in small towns, from which students will be referred to schools in larger cities. This will require remodelling the public transport system and may lead to greater car dependency. Older people pay attention to different aspects than other passengers. Some of the important factors for them include adequate passenger information, the politeness of drivers and the way they drive their vehicles, as well as the level of comfort and safety during the journey. Taking into account the demands of the elderly will require a change in the current approach to public transport management. Considering the fact that a large proportion of elderly people previously used private cars for daily travel, it will be necessary to implement educational programmes to present the

Table 10
Demographic changes and determinants of public transport policy. Source: Urbanek and Krawczyk (2018); Holley-More and Creighton (2015); Hounsell et al. (2016), Shiau and Huang (2014); Hansson and Holmgren (2017); Mackett (2015); Metz (2003a, 2003b); Fatima et al. (2020), Dickerson et al. (2019).

Area of influence	Expected changes	Effects on the public transport system
Revenue of public transport organizers	Decrease in public transport demand Decrease in public revenues from taxes Decreasing group of people paying full fares Extension of fare concessions for the elderly The need to increase the frequency of services in the periods between peak times	Decline in revenues of public transport organizers Increase in public funding
Operating expenditures	Pressure to implement “on-demand” transport	Increase in operating expenditures of public transport organizers
Capital expenditures	Modernization of the public transport fleet Adaptation of infrastructure	Increase in capital expenditures of public transport organizers, operators and infrastructure managers
Planning and management	Decrease in the number of students/pupils Changes in public transport routes Fluctuating demand for services Training for drivers More accessible passenger information Increased comfort and safety Increasing importance of educational and promotional activities in the use of the transport system Cooperation with organizations representing elderly people	Changing the way public transport is managed

public transport services on offer and build trust in the system (Cirella et al., 2019).

The results of our study show that the consequences of demographic changes need to be taken into consideration now in the process of policymaking. Many investment plans for infrastructure development and urban planning need to be reconsidered, as they require a long-term and holistic approach to mobility planning that includes the impact of demographic changes.

5.2. Strengths and limitations of the study

The conducted study has the advantage of a big dataset originating from a large research sample in the metropolitan area. This allowed us to conduct a robust analysis that covers not only the level of mobility measured by the number of daily trips, travel time and distance, but also by mode choice factors in all age groups.

Although statistical inference is of course limited to the studied area, the research results can be extrapolated to other cities and metropolitan areas that struggle with many problems common for other cities and metropolitan areas in Europe (ageing population, increasing road congestion and decreasing share of public transport). Moreover, it should be noted that the proposed approach can also be modified and adapted for the purposes of further research work.

The study and its conclusions rely heavily on the population projection developed by Statistics Poland, the reliability of which is difficult to assess. As at the regional level, only one, central variant of the projection is published, it is impossible to run robustness checks using alternative projections. Nevertheless, even in the most optimistic variant of the country-level projections, the substantial population drop is expected to amount to about half of the drop predicted in the baseline variant and the studied region is likely to be subject to a similar effect. Therefore, we believe that our principal conclusion that depopulation will be the main demographic driving force for the transport system is likely to also hold for other projection variants.

Of course, the projections developed in our study cannot be treated as an accurate guideline for policymakers, since they miss several important factors that are likely to influence the aggregate transport needs, especially given the long horizon of the projections. Instead, they only serve the purpose of estimating the aggregate impact of ageing, showing that it is likely to be much smaller for our area, as compared with depopulation.

CRediT authorship contribution statement

Anna Urbanek: Conceptualization, Data curation, Methodology, Writing – review & editing, Supervision, Project administration, Validation, Investigation. **Jan Acedański:** Methodology, Data curation, Formal analysis, Writing – review & editing, Validation, Visualization. **Grzegorz Krawczyk:** Conceptualization, Data curation, Methodology, Writing – review & editing, Investigation, Validation, Visualization.

Declaration of Competing Interest

None.

Data availability

The authors do not have permission to share data.

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References

- Abdelfattah, L., Deponte, D., Fossa, G., 2022. The 15-minute city: interpreting the model to bring out urban resiliencies. *Transp. Res. Procedia* 60. <https://doi.org/10.1016/j.trpro.2021.12.043>.
- Ahrens, G.A., 2005. Demographic changes—consequences for the transportation sector. *J. Public Health* 13, 16–21. <https://doi.org/10.1007/s10389-004-0080-z>.
- Alamá-Sabater, L., Budí, V., Roig-Tierno, N., García-Álvarez-Coque, J.M., 2021. Drivers of depopulation and spatial interdependence in a regional context. *Cities* 114, 103217. <https://doi.org/10.1016/j.cities.2021.103217>.
- Banister, D., Bowling, A., 2004. Quality of life for the elderly: the transport dimension. *Transp. Policy* 11, 105–115.
- Bardazzi, R., Paziienza, M.G., 2018. Ageing and private transport fuel expenditure: do generations matter? *Energy Policy* 117, 396–405. <https://doi.org/10.1016/j.enpol.2018.03.026>.
- Boschmann, E.E., Brady, S.A., 2013. Travel behaviors, sustainable mobility, and transit oriented developments: a travel counts analysis of older adults in the Denver, Colorado metropolitan area. *J. Transp. Geogr.* 33, 1–11.
- Box, E., Gandolfi, J., Mitchell, K., 2010. Maintaining Safe Mobility for the Aging Population – The Role of the Private Car. RAC Foundation, London. http://www.racfoundation.org/assets/rac_foundation/content/downloadables/maintaining%20safe%20mobility%20-%20rac%20foundation%20-%20140410%20-%20report.pdf.
- Buehler, R., Nobis, C., 2010. Travel Behavior in Aging Societies Comparison of Germany and the United States, Transportation Research Record: Journal of the Transportation Research Board, No. 2182. Transportation Research Board of the National Academies, pp. 62–70. <https://doi.org/10.3141/2182-09>.
- Cao, X., Handy, S., Mokhtarian, P.L., 2007. Residential and travel choices of elderly residents of Northern California. In: Proceedings of the 48th Annual Transportation Research Forum, Boston. https://www.researchgate.net/publication/228419351_Residential_and_Travel_Choices_of_Elderly_Residents_of_Northern_California.
- Cao, X., Mokhtarian, P.L., Handy, S.L., 2010. Neighborhood design and the accessibility of the elderly: an empirical analysis in Northern California. *Int. J. Sustain. Transp.* 4, 347–371.
- Caselli, B., Carra, M., Rossetti, S., Zazzi, M., 2022. Transportation Research Procedia, vol. 60. <https://doi.org/10.1016/j.trpro.2021.12.045>.
- Christensen, K., Doblhammer, G., Rau, R., Vaupel, J.W., 2009. Ageing populations: the challenges ahead. *Lancet* 374, 1196–1208.
- Christidis, P., Navajas, E., Brons, M., Schade, B., Mongeli, I., Soria, A., 2014. Future employment in transport - Analysis of labour supply and demand. <http://publication.s.jrc.ec.europa.eu/repository/bitstream/JRC93302/move%20to%20jobs%20-%20jrc%20final%20report%20final%2020150113.pdf>.
- Chudyk, A.M., Winters, M., Moniruzzaman, M., Ashe, M.C., Gould, J.S., McKay, H., 2015. Destinations matter: the association between where older adults live and their travel behavior. *J. Transp. Health* 2 (1), 50–57.
- Cirella, G.T., Bak, M., Kozlak, A., Pawlowska, B., Borkowski, P., 2019. Transport innovations for elderly people. *Res. Transp. Bus. Manag.* 30, 100381 <https://doi.org/10.1016/j.rtbm.2019.100381>.
- Currie, G., Delbosc, A., 2010. Exploring public transport usage trends in an ageing population. *Transportation* 37, 151–164. <https://doi.org/10.1007/s11116-009-9224-x>.
- Dickerson, A.E., Molnar, L.J., Bedard, M., Eby, D.W., Berg-Weger, M., Choi, M., Grigg, J., Horowitz, A., Meuser, T., Myers, A., O'Connor, M., Silverstein, N.M., 2019. Transportation and aging: an updated research agenda to advance safe mobility among older adults transitioning from driving to non-driving. *Gerontol.* 59, 215–221. <https://doi.org/10.1093/geront/gnx120>.
- Dit, Asse M., Fabrigoule, L., Helmer, C., Laumon, B., Lafont, S., 2014. Automobile driving in older adults: factors affecting driving restriction in men and women. *J. Am. Geriatr. Soc.* 62 (11), 2071–2078. <https://doi.org/10.1111/jgs.13077>.
- Driscoll, R.A., Lehmann, K.R., Polzin, S., Godfrey, J., 2018. The effect of demographic changes on transit ridership trends. *Transp. Res. Rec.* 2672 (8), 870–878. <https://doi.org/10.1177/0361198118777605>.
- EMTA (European Metropolitan Transport Authorities), 2007. Older People and Public Transport, 48–49. https://www.emta.com/IMG/pdf/Final_Report_Older_People_protect.pdf.
- Eriksson, L., Garvill, J., Nordlund, A.M., 2008. Interrupting habitual car use: the importance of car habit strength and moral motivation for personal car use reduction. *Transport. Res. F: Traffic Psychol. Behav.* 11 (1), 10–23. <https://doi.org/10.1016/j.trf.2007.05.004>.
- European Commission, 2020. European Commission Report on the Impact of Demographic Change. https://ec.europa.eu/info/sites/info/files/demography_report_2020.pdf.
- Eurostat, 2020. Population age structure by major age groups, 2009 and 2019. [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Populati_on_age_structure_by_major_age_groups_2009_and_2019_\(%25_of_the_total_populati_on\).png#filehistory](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Populati_on_age_structure_by_major_age_groups_2009_and_2019_(%25_of_the_total_populati_on).png#filehistory).
- Fatima, K., Moridpour, S., De Gruyter, C., Saghapour, T., 2020. Elderly sustainable mobility: scientific paper review. *Sustainability* 12, 7319. <https://doi.org/10.3390/su12187319>.
- Figueroa, M.J., Nielsen, T.A.S., Siren, A., 2014. Comparing urban form correlations of the travel patterns of older and younger adults. *Transp. Policy* 35, 10–20.
- Greene, W.H., 2012. *Econometric Analysis*, Seventh edition. Pearson, Boston, London.
- Haartsen, T., van Wissen, L., 2012. Causes and consequences of regional population decline for primary schools. *J. Econ. Hum. Geogr.* 103 (4) <https://doi.org/10.1111/j.1467-9663.2012.00736.x>.
- Hansson, L., Holmgren, J., 2017. Reducing dependency on special transport services through public transport. *Transp. Res. Procedia* 25, 2450–2460. <https://doi.org/10.1016/j.trpro.2017.05.263>.
- Haustein, S., Siren, A., Framke, E., Bell, D., Pokriefke, E., Alauzet, A., Marin-Lamellet, C., Armoguum, J., O'Neill, D., 2013. Demographic change and transport. In: CONSOL. European Commission — Directorate-General for Mobility and Transport, pp. 23–24. Available at: http://www.consolproject.eu/attachments/article/15/CONSOL%20Report_WP1_final.pdf.
- Hebel, K., Wolek, M., 2021. Methodology for the evaluation of walking trips among the inhabitants in the light of marketing research results in Warsaw and Gdynia (Poland). In: Suchanek, M. (Ed.), *Transport Development Challenges in the 21st Century. Proceedings of the 2019 TransSopot Conference*. Springer Proceedings in Business and Economics, Springer International Publishing. <https://doi.org/10.1007/978-3-030-50010-8>.
- Hensher, D.A., 2007. Some insights into the key influences on trip-chaining activity and public transport use of seniors and the elderly. *Int. J. Sustain. Transp.* 1, 53–68. <https://doi.org/10.1080/15568310601097004>.
- Hensher, D.A., Prioni, P., 2002. A service quality index for area-wide contract performance assessment. *J. Transp. Econ. Policy* 36 (1), 93–113. www.jstor.org/stable/20053894.
- Hildebrand, E.D., 2003. Dimensions in elderly travel behaviour: a simplified activity-based model using lifestyle clusters. *Transportation* 30, 285–306. <https://doi.org/10.1023/A:102394930747>.
- Hjorthol, R.J., Levin, L., Siren, A., 2010. Mobility in different generations of older persons the development of daily travel in different cohorts in Denmark, Norway and Sweden. *J. Transp. Geogr.* 18 (5), 624–633. <https://doi.org/10.1016/j.jtrangeo.2010.03.011>.
- Holley-More, G., Creighton, H., 2015. The Future of Transport in an Ageing Society. International Longevity Centre, UK. <https://oldermobility.com/download/31/transport-planning/2703/the-future-of-transport-in-an-ageing-society-george-holley-moore-and-helen-creighton.pdf>.
- Hosmer, D.W., Lemeshow, S., 2000. *Applied Logistic Regression*, Second edition. John Wiley & Sons, New York.
- Hounsell, N.B., Shrestha, B.P., McDonald, M., Wong, A., 2016. Open data and the needs of older people for public transport information. *Transp. Res. Procedia* 14, 4334–4343. <https://doi.org/10.1016/j.trpro.2016.05.355>.
- Hylton, S.A., 2016. Issues with Lack of Transportation Supports for Suburban Dwelling Older Adults: A Modern Conundrum. Honors Theses, 124, pp. 2–25. https://digitalcommons.salestate.edu/honors_theses/124.
- Jittrapirom, P., Neervan, W.V., Martens, K., Trampe, D., Meurs, H., 2019. The Dutch elderly's preferences toward a smart demand-responsive transport service. *Res. Transp. Bus. Manag.* 30, 100383 <https://doi.org/10.13140/RG.2.2.32215.62889>.
- King, W.C., Brach, J.S., Belle, S., Killingsworth, R., Fenton, M., Kriska, A.M., 2003. The relationship between convenience of destinations and walking levels in older women. *Am. J. Health Promot.* 18, 74–82.
- Kizony, R., Schreuer, N., Rotenberg, S., Shach-Pinsky, D., Sinoff, G., Plaut, P., 2020. Participation in out-of-home activities among older adults: the role of mobility, attitudes and travel behaviors. *J. Transp. Health* 17, 100846. <https://doi.org/10.1016/j.jth.2020.100846>.
- Kostełcka, A., Pietrzak, K., Brzeziński, B., Strzebrakowska, B., Thiem, J., Thiem, J., Maćkowiak, A., Budny, R., Kempa, B., Krakowski, Ł., Popławski, M., 2018. Transport study for the central subregion of the Silesian Voivodeship. In: *Research Results – Report from the Stage 4a of the Study*, PBS-BIT-IMS, Sopot/Poznań/Kraków (in Polish).
- Liu, W., Lu, H., Sun, Z., Liu, J., 2017. Elderly's travel patterns and trends: the empirical analysis of Beijing. *Sustainability* 9 (6), 981. <https://doi.org/10.3390/su9060981>.
- Luiu, C., Tight, M., Burrow, M., 2018. Factors preventing the use of alternative transport modes to the car in later life. *Sustainability* 2018 (10), 1982. <https://doi.org/10.3390/su10061982>.
- Mackett, R., 2015. Improving accessibility for older people – investing in a valuable asset. *J. Transp. Health* 2 (1), 5–13. <https://doi.org/10.1016/j.jth.2014.10.004>.
- McArthur, D.P., Thorsen, I., Uboe, J., 2014. Employment, transport infrastructure, and rural depopulation: a new spatial equilibrium model. *Environ. Plan. A* 46. <https://doi.org/10.1068/a46120>.
- Mercado, R., Páez, A., Newbold, K.B., 2010. Transport policy and the provision of mobility options in an aging society: a case study of Ontario, Canada. *J. Transp. Geogr.* 18 (5), 649–661. <https://doi.org/10.1016/j.jtrangeo.2010.03.017>.
- Metz, D., 2003a. Transport policy for an ageing population. *Transp. Rev.* 23 (4), 375–386. <https://doi.org/10.1080/0144164032000048573>.
- Metz, D., 2003b. Transport policy for an ageing population. *Transp. Rev. A Transl. Transdiscipl. J.* 23 (4), 375–386. <https://doi.org/10.1080/0144164032000048573>.
- Metz, D., 2012. Demographic determinants of daily travel demand. *Transp. Policy* 21, 20–25. <https://doi.org/10.1016/j.tranpol.2012.01.007>.
- Newbold, K.B., Scott, D.M., Spinney, J.E.L., Kanaroglou, P., Paez, A., 2005. Travel behavior within Canada's older population: a cohort analysis. *J. Transp. Geogr.* 13, 340–351.
- Nordbakke, S., 2013. Capabilities for mobility among urban older women: barriers, strategies and options. *J. Transp. Geogr.* 26, 166–174. <https://doi.org/10.1016/j.jtrangeo.2012.10.003>.
- O'Fallon, C., Sullivan, C., 2009. Trends in older people's travel patterns: analysing changes in older New Zealanders' travel patterns using the Ongoing New Zealand Household Travel Survey. In: *NZ Transport Agency Research Report* 369. <http://www.nzta.govt.nz/resources/research/reports/369/docs/369.pdf>.

- O'Hern, S., Oxley, J., 2015. Understanding travel patterns to support safe active transport for old adults. *J. Transp. Health* 2 (1), 79–85.
- Pettersson, P., Schmöcker, J.-D., 2010. Active ageing in developing countries? – trip generation and tour complexity of older people in Metro Manila. *J. Transp. Geogr.* 18 (5), 613–623. <https://doi.org/10.1016/j.jtrangeo.2010.03.015>.
- Pettigrew, S., Cronin, S.L., Norman, R., 2019. Brief report: the unrealized potential of autonomous vehicles for an aging population. *J. Aging Soc. Policy* 31 (5), 486–496. <https://doi.org/10.1080/08959420.2018.1500860>.
- Pomoni, M., Laiou, A., Plati, C., Yannis, G., Loukea, M., Bekiaris, E., 2020. Future trends in transport workforce based on demographic, behavioural, cultural and socioeconomic factors. *Transp. Res. Procedia* 48, 2811–2820. <https://doi.org/10.1016/j.trpro.2020.08.237>.
- Pristavec, T., 2016. Social participation in later years: the role of driving mobility. *J. Gerontol.* B 73, 1457–1469. <https://doi.org/10.1093/geronb/gbw057>.
- Raitanen, T., Törmäkangas, T., Mollenkopf, H., Marcellini, F., 2003. Why do older drivers reduce driving? Findings from three European countries. *Transport. Res. F: Traffic Psychol. Behav.* 6, 81–95.
- Redman, L., Friman, M., Gärling, T., Hartig, T., 2013. Quality attributes of public transport that attract car users: a research review. *Transp. Policy* 25, 119–127. <https://doi.org/10.1016/j.tranpol.2012.11.005>.
- Rees, C., Lyth, A., 2004. Exploring the future of car use for an ageing society: Preliminary results from a Sydney study. In: Paper presented at the 27th Australasian Transport Research Forum, Adelaide, 29 Sep–1 Oct 2004. https://www.researchgate.net/publication/37183730_Exploring_the_future_of_car_use_for_an_ageing_society_Preliminary_results_from_a_Sydney_study.
- Risser, R., Haindl, G., Ståhl, A., 2010. Barriers to senior citizens' outdoor mobility in Europe. *Eur. J. Ageing* 7, 69–80.
- Rosenbloom, S., 2001. Sustainability and automobility among the elderly: an international assessment. *Transportation* 29, 375–408.
- Ryan, J., Wretstrand, A., Schmidt, S.M., 2019. Disparities in mobility among older people: findings from a capability-based travel survey. *Transp. Policy* 79, 177–192. <https://doi.org/10.1016/j.tranpol.2019.04.016>.
- Sammer, G., Gruber, Ch., Roeschel, G., Tomschy, R., Herry, M., 2018. The dilemma of systematic underreporting of travel behavior when conducting travel diary surveys – a meta-analysis and methodological considerations to solve the problem. *Transp. Res. Procedia* 32, 649–658. <https://doi.org/10.1016/j.trpro.2018.10.006>.
- Schwane, T., Páez, A., 2010. The mobility of older people – an introduction. *J. Transp. Geogr.* 18 (5), 591–595. <https://doi.org/10.1016/j.jtrangeo.2010.06.001>.
- Shiau, T.A., Huang, W.K., 2014. User perspective of age-friendly transportation: a case study of Taipei City. *Transp. Policy* 36, 184–191. <https://doi.org/10.1016/j.tranpol.2014.08.010>.
- Shresta, B.P., Millonig, A., Hounsell, N.B., McDonald, M., 2017. Review of public transport needs of older people in European context. *Popul. Ageing* 10, 343–361. <https://doi.org/10.1007/s12062-016-9168-9>.
- Siren, A., Hakamies-Blomqvist, L., 2004. Grand equaliser? Demographic factors and mobility in Finnish men and women aged 65+. *Transport. Res. F: Traffic Psychol. Behav.* 7 (2), 59–134. <https://doi.org/10.1016/j.trf.2004.02.003>.
- Siren, A., Hauste, S., 2013. Baby boomers' mobility patterns and preferences: what are the implications for future transport? *Transp. Policy* 29, 136–144. <https://doi.org/10.1016/j.tranpol.2013.05.001>.
- Smith, G.C., Sylvestre, G.M., 2001. Determinants of the travel behavior of suburban elderly. *Growth Chang.* 32, 395–412.
- Spielberg, F., Andrie, S., 1982. The implications of demographic changes on transportation policy. *J. Am. Plan. Assoc.* 48 (3), 301–308. <https://doi.org/10.1080/01944368208976179>.
- Štašná, M., Vaishar, A., 2017. The relationship between public transport and the progressive development of rural areas. *Land Use Policy* 67. <https://doi.org/10.1016/j.landusepol.2017.05.022>.
- Statistics Poland, 2014. Prognoza dla powiatów i miast na prawie powiatu oraz podregionów na lata 2014–2050. <https://stat.gov.pl/obszary-tematyczne/ludnosc/prognoza-ludnosci/prognoza-dla-powiatow-i-miast-na-prawie-powiatu-oraz-podregionow-na-lata-2014-2050-opracowana-w-2014-r-,5,5.html>.
- Statistics Poland Database, 2023. <https://bdl.stat.gov.pl/BDL/start>.
- Stopher, P., Greaves, S., Clifford, E., 2007. Multi-day Household Travel Survey: Sampling Issues, 30th Australasian Transport Research Forum. https://www.australasiantransportresearchforum.org.au/sites/default/files/2007_Clifford_Greaves_Stopher.pdf.
- Su, F., Bell, M.G.H., 2012. Travel differences by gender for older people in London. *Res. Transp. Econ.* 34 (1), 35–38. <https://doi.org/10.1016/j.retrec.2011.12.011>.
- Toole-Holt, L., Polzin, S.E., Pendyala, R.M., 2005. Two minutes per person per day each year: exploration of growth in travel time expenditures. *Transp. Res. Rec.* 1917, 45–53. <https://doi.org/10.1177/0361198105191700106>.
- Truong, L.T., Somenahalli, S., 2011. Exploring mobility of older people: A case study of Adelaide. In: *Australasian Transport Research Forum 2011 Proceedings 28–30 September 2011, Adelaide, Australia*.
- Urbanek, A., Krawczyk, G., 2018. Ageing Societies – Economic Consequences for Public Transport. Proceedings of 8th International Scientific Conference CMDTUR 2018, Zilina, pp. 307–314. https://www.researchgate.net/publication/331160113_Ageing_Societies_-_Economic_Consequences_for_Public_Transport.
- Verplanken, B., Aarts, H., van Knippenberg, A., Moonen, A., 1998. Habit versus planned behavior: a field experiment. *Br. J. Soc. Psychol.* 37, 111–128. <https://doi.org/10.1111/j.2044-8309.1998.tb01160.x>.
- Webb, E., Laverty, A., Mindell, J., Millett, C., 2016. Free bus travel and physical activity, gait speed, and adiposity in the English longitudinal study of ageing. *Am. J. Public Health* 106, 136–142. <https://doi.org/10.2105/AJPH.2015.302907>.
- Webber, S.C., Porter, M.M., Menec, V.H., 2010. Mobility in older adults: a comprehensive framework. *Gerontologist* 50, 443–450.
- Whelan, M., Langford, J., Oxley, J., Koppel, S., Charlton, J., 2006. The Elderly and Mobility. A Review of the Literature. Report Nr. 255. Monash University Accident Research Center. <http://www.monash.edu.au/miri/research/reports/maarc255.pdf>.
- WHO (World Health Organization), 2008. Men, ageing and health. Geneva, pp. 10–12. https://apps.who.int/iris/bitstream/handle/10665/66941/WHO_NMH_NPH_01.2.pdf.
- Yang, J., Coughlin, J.F., 2014. In-vehicle technology for self-driving cars: advantages and challenges for aging drivers. *Int. J. Automot. Technol.* 15, 333–340. <https://doi.org/10.1007/s12239-014-0034-6>.
- Yang, Y., Xu, Y., Rodriguez, D.A., Michael, Y., Zhang, H., 2018. Active travel, public transportation use, and daily transport among older adults: the association of built environment. *J. Transp. Health* 9, 288–298. <https://doi.org/10.1016/j.jth.2018.01.012>.
- Ye, X., Pendyala, R.M., Gottardi, G., 2007. An exploration of the relationship between mode choice and complexity of trip chaining patterns. *Transp. Res. B Methodol.* 41 (1), 96–113. <https://doi.org/10.1016/j.trb.2006.03.004>.