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Combination of traditional and new methods for the analysis of travel patterns: the case of nationwide public transport OD matrices in Hungary

András Munkácsy[a]*, Vilmos Oszter[a]

[a]*KTI Institute for Transport Sciences NLtd.; Than Károly u. 3–5, Budapest, 1119; Hungary*

Abstract

Big data is a keyword of current and future trends in transport planning. However, despite recent developments and diffusion of smart technology based e-ticketing (e.g. by access cards) and systems for tracking passenger movements by mobile devices, their use is still not common in European countries. Thus, currently both classical and novel surveying and data processing methods are used to estimate origin-destination (OD) matrices in interurban public transport in some countries like Hungary, where nationwide OD matrices are pillars of strategy-making and planning.

In 2016-2017, nearly ten years after the last update, new interurban public transport passenger OD matrices have been elaborated in Hungary, including all trips on non-local bus and train services on a weekday in autumn 2016. Although public passenger transport services are provided by state-owned companies (a national and a regional railway operator as well as seven regional bus companies) and a handful of small private operators, there is no standardized data collection or integrated ticketing.

Consequently survey methods of cross-sectional passenger counts and personal OD interviews have been combined with electronic ticket sales data to build a database. Trip chains and travel patterns of a sample of more than 100,000 passengers have been surveyed on buses, trains and major interchanges. Data has been processed to generate OD matrices of direct trips using the method of conversion and to integrate (bus↔bus and bus↔train) transfers using probability estimation techniques. Matrices have been estimated by transport mode, on both regional and national level, including a comprehensive national public transport OD matrix.

In this contribution, the novel combination of data collection techniques to realize a nationwide survey, data processing methodology as well as key findings (especially main traffic flows and travel patterns) are presented.

Keywords: Public Transport (5), Rural and Interurban (5), Intermodality (5), Travel survey, Hungary

* Corresponding author. Tel.: +36-1-371-5988
E-mail address: munkacsy.andras@kti.hu

1. Introduction

Studies assessing travel patterns in public transport are key components to offer efficient mobility solutions. Data analysis from travel surveys combined with the relevant socio-economic indicators is necessary to make strategic decisions on further development of public transport. Travel data about passengers' flows as well as modal split information have to be updated from time to time to provide designers and scholars with actual information to support these decisions.

Origin-destination (OD) estimation is a relatively well-researched topic of transport planning. First, especially in the 1980s and 1990s, studies focused on estimations on the basis of scarce, diverse and low reliability data (Cascetta, 1984; Nguyen, 1984; Van Zuylen and Willumsen, 1980; Yang et al., 1992). From the late 1990s, there is growing interest in automated data collection procedures and data from e-ticketing systems (Alsger et al., 2016; Cui, 2006; Farzin, 2008; Munizaga and Palma, 2012; Trépanier et al., 2007; Wang et al., 2011; Zijpp, 1997).

In Hungary, nationwide road vehicle OD matrices have been elaborated approximately in every ten years since the 1950s, on the basis of traditional transport surveys. In 2007-2008, nationwide passenger OD matrices were also estimated for interurban passenger trips on trains and buses (Albert, 2017; Albert et al., 2009). This paper describes the recent update of the passenger OD database, i.e. methods and essential results of travel patterns and main trip directions. Although e-ticketing has not yet been introduced in Hungary, results are largely based on electronically processed ticket data and complementary traditional data collections from different sources, including ticketing sales statistics, passenger counts and personal interviews on-board vehicles and at major terminals and interchanges. The nationwide travel survey took place in October and November 2016 and OD estimations were carried out in 2017, as part of the EU-funded "Enhancing the participation of Hungary in the TEN-T Corridors" action for the development of multimodal (road, rail, air, inland navigation) OD matrices in Hungary.

The paper summarizes the elaboration of OD matrices (data sources and applied methods), as well as briefly presents results about trips and travel patterns of passengers of interurban public transport (rail and bus) in Hungary on a weekday.

2. Data sources

In Hungary – an EU-member country of approx. 9.8 million inhabitants and 93 thousand km^2 in Central Europe – suburban, interurban, regional and long-distance (called *interurban* in this paper) scheduled public transport passenger services are managed by a central authority. Financial compensation is provided through public service obligation (PSO) contracts between the authority (Ministry of National Development, i.e. ministry for transport) and a contractor. Two passenger railway operators, seven large regional bus operator companies (and their minor subcontractors) and a handful of small bus companies operate regular interurban public transport services.

Based on experiences of previous travel surveys, timing of data collection was adjusted to the period with most regular travel demand, which is a typical working day in the spring or autumn period without any major holiday nearby. Therefore working days (Tuesdays, Wednesdays or Thursdays) in the first half of October and November of 2016 have been selected for the survey. (In one region, travel survey on buses took place as a pilot action of the national data collection, in April 2016).

2.1. One-day extended ticket sale for all interurban passengers

Due to the centrally regulated fare system, several social groups are entitled for discounted fare tickets which include free of charge option for a large proportion of passengers. As a general rule, EU citizens older than 65 years of age are exempt from paying for public transport in Hungary, without the need for any registration, by only showing their national ID card or passport for inspection. Together with other less numerous social groups (children under 6, refugees, etc.) they form a significant group of passengers whose trips do not appear in ticket statistics; furthermore, their distribution by origins and destinations (or public transport lines) is varied. Frequent travellers with regular pass are registered monthly but their actual travel patterns (frequency, origin and destination) are unknown due to the distance (and not OD) based issuing of passes. In order to reveal their trip patterns, a special ticket was registered by ticket vending machines on-board (operated by the driver) for regular pass holders and all passengers travelling free of charge. The extended ticket sale was realised on one working day per public transport region (i.e. per regional bus operator). Ticket data was processed and forwarded by the operators by the main ticket categories (travel pass, student travel pass, full ticket, reduced fare, free of charge). Due to the several types of ticket selling machines used, software adjustments and technical developments had to be done in some cases, as well.

2.2. On-board passenger counts on some bus services

In certain cases, mostly on some overcrowded suburban peak-hour services served by articulated buses, there was no time for emitting statistical registration tickets for pass holders and free travellers. For these ca. 600 services, full-scale cross-sectional boarding and alighting data collected by on-board counter staff has been used.

2.3. Passenger interviews

By technical reasons, bus ticket selling machines were not able to register transfers of passengers between buses or other modes. In order to collect information about the full trip chains, personal interviews were carried out. Based on the previous nationwide OD travel survey results and the consultations realized by the regional bus operator companies, 94 bus stations (terminals and major bus↔rail interchanges) and some bus services have been selected all along Hungary. Interviewers addressed primarily passengers waiting for boarding (or travelling on-board buses) and asked questions about their ongoing trip chain, recording sex, age group, purpose of the trip, ticket used, frequency of the trip and also the access and egress modes to the public transport mean. The questionnaires were filled in during 12 hours per location on the same day when the above mentioned extended ticket sale and/or onboard counting took place. In total, 67,676 interviews have been done.

A nearly identical questionnaire has been used to reveal travel patterns of passengers on-board trains. The exact stops including transfer stations were asked from 4 am till 11 pm on regional and long-distance services and from 12 pm till 10 pm on Budapest suburban services from Tuesday till Thursday in October and November. A sample of 33,733 passengers has been interviewed: 30% on the suburban network of Budapest on-board of 418 trains and 70% on 1,124 long-distance and regional trains nationwide. This is nearly 8% of the total number of passengers on trains, but there are underrepresented (2-4% of passengers of busy suburban commuter services) and fully represented trains (100% of some regional branch lines with low passenger demand). Nevertheless, results contain data for all lines with exception of two major planned closure sections and four extremely low traffic branch lines. Three suburban railway lines (HÉV) around Budapest have not been taken into account, since its takeover by a national railway operator from a local service provider was ongoing during the project.

2.4. Railway ticketing data

Since 2011, nearly all domestic passenger railway ticket is issued electronically using a joint IT background of the two operator companies (MÁV-START and GYSEV). Currently there are only few sections operated by GYSEV with some low traffic stops and stations without e-ticket vending options, and therefore ticket controllers on these lines still issue tickets manually. Thus OD data is not known exactly there, only types of tickets and lengths of journeys. All other journeys, which represent more than 99% of the trips, are recorded electronically for types of tickets and exact OD pairs, including transfer within rail services.

MÁV-START has an ongoing e-ticket project which will allow to check the exact use of tickets and monthly passes per train and date, but at the time of this OD survey the project had only partial employment in practice. Accordingly, monthly pass (season ticket) holders are considered taking 26 return trips on the given section of their pass validity (in line with the accounting of season tickets in service contracts). From previous surveys (Albert et al, 2009), it is known that around 90% of these commuter trips are realised on weekdays.

The main uncertainty in this dataset comes from the trip patterns of passengers who travel free of charge due to the widespread social discount system, as it was mentioned above. In order to obtain the share of free travelers on each railway OD relations, registration ticket data per OD relations of 2011 (the only full year when there was mandatory registration of all trips, i.e. purchasing free tickets) has been used. According to the travel surveys, an average of 15% of the passengers did not buy tickets due to their age in 2016.

3. Methods

On some bus services, traditional passenger counts replaced electronically processed ticket information. A shortcoming of counting only the number of boarding and alighting passengers is providing only cross-sectional (no. of passengers between two stops) and not OD information. To estimate OD, the previously developed method of *conversion* (konverzió) has been used (Albert and Vass, 2009; Vass, 2001), which combines full-scale passenger counts with a sample of OD information.

In the dataset provided by operators, bus↔bus and bus↔train transfers are not included: successive legs of a trip chain are presented as individual trips. For a more realistic OD matrix, information on transfers (destinations, no. of passengers) is needed, which is based on travel surveys in this research. In order to reveal complex trips, passenger interviews were carried out at interchanges (especially, interurban bus terminals) and on-board trains and some bus services. Only trip chains with two legs have been included, since trips with more legs (with more than one transfer) are rare in interurban journeys (0.05% among 67,676 survey respondents on the bus network) and may be considered irregular (four out of five of these trips are not done on daily basis and two out of three are not trips to work or school), thus their role is insignificant in daily mobility.

3.1. OD estimation of trips without transfer

Conversion is the estimation of OD of a certain bus service from the data of cross-sectional counts (no. of boarding and alighting in stops) using temporary probabilities. As trip characteristics are only partially known (there is no actual information on the destination of a passenger with certain origin and vice versa), trips are estimated similarly to the estimation of the value of a random variable. Assuming that alighting of a passenger boarding in a certain stop is a random phenomenon (if there is no other information in the cross-sectional data), this method makes passengers alight randomly, simulating alighting by Monte Carlo methods.

As a general rule, conversion requires an OD sample from each bus service (by personal interviews or other survey methods) but in this case only a limited sample was available. Thus temporary probabilities have been counted from 1) data of passenger interviews in major terminals and interchanges, as well as on-board services, 2) electronically processed ticket data, 3) passenger movements of the service, 4) data of the last (full-scale) national travel survey in 2007-2008.

In equation (1), phenomenon {A B} means that a passenger boards in settlement A and alights in B, and its probability is P(A B). Phenomenon {B|A} is the conditional probability of alighting in B, if the passenger boards in A, and its probability is P(B|A). In this context, $P(D_j|O_i)$ is the temporary probability for a certain boarding stop (origin). This is calculated on the basis of the cross-sectional dataset and the above mentioned temporary probabilities for passengers travelling between two settlements of a certain service. This is used for the simulation of alighting, i.e. estimation of OD of trips of passengers (excluding transfers).

$$P(D_j|O_i) = \frac{P(S_O\, D_j)}{\sum_i P(O_i)} = \frac{U}{\sum_i o_i} \times \frac{d_j}{\sum_{j'} d_{j'}} \times P(S_O\, S_D) \quad (1)$$

In which S_O is the boarding (origin) settlement; S_D is the alighting (destination) settlement; D_j is the stop number j of settlement S_D; O_i is the stop number i in settlement S_O; U is the total number of passengers on a service; o_i is the number of passengers boarding in settlement O_i (according to the cross-sectional dataset); d_j is the number of passenger alighting in stop D_j (according to the cross-sectional dataset); $P(S_O\, S_D)$ is a temporary probability (according to points 1) to 4) above).

3.2. OD estimation of trips with transfer

To estimate the number of transfers between two stops or in the present case, between two settlements, the method developed for this kind of datasets have been used (Munkácsy and Vass, 2017; Vass, 2013). The estimated transfer rate is equal to the weighted average of transfer rates (a certain number of chosen discrete values between 0 and 1) that has been calculated using the probability of transfers in the sample as weights. This is a simple random sample and the probability variable, i.e. frequency of transfers has hypergeometric distribution. Sample population is 1) the number of boarding passengers of the service in case of surveying in bus terminals and interchanges and

2) the average number of passengers (weighted by travel time between stops) in case of on-board interviewing. Full population is calculated from ticket statistics and cross-sectional counts.

Proportion of transfers in the sample to the given population has been estimated for actual pairs of services (from/to the passenger transfers), assuming the hypergeometric distribution of sample items including transfers. Full rate of transfers has been estimated including services without information in the sample, extrapolating transfer rates of all services from a certain stop. Probability distribution function for the identification of transfer rates may be seen as equation (2).

$$\mathrm{H}(\mathrm{k};\mathrm{N},\mathrm{M},\mathrm{n}) = \binom{\mathrm{M}}{\mathrm{k}}\frac{\binom{\mathrm{N}-\mathrm{M}}{\mathrm{n}-\mathrm{k}}}{\binom{\mathrm{N}}{\mathrm{n}}} \tag{2}$$

In which k is the number of transfers in the sample; n is sample size; N is population size (see above); M is the number of transfers: $\mathrm{M} = \mathrm{p} \times \mathrm{N}$ in case of on-board surveys and $\mathrm{M} = \mathrm{p} \times \mathrm{U}$ in case of surveying at interchanges or bus terminals; U is the number of passengers to the destination, if the survey takes place where the passenger transfers from one service to another or the number of passengers alighting in the transfer stop, if the survey takes place before boarding the first service; and p is the transfer rate.

Estimation of p is a weighted average ($\hat{\mathrm{p}}$), see equation (3).

$$\hat{\mathrm{p}}^{\mathrm{S_F S_L}} = \sum_{\mathrm{i}} \mathrm{p_i} \times \mathrm{H}\left(\mathrm{k}_0^{\mathrm{S_F S_L}};\mathrm{N},\mathrm{M_i},\mathrm{n}\right) \tag{3}$$

This estimation is made between $\mathrm{S_F}$ (a certain settlement of the first service) and $\mathrm{S_L}$ (a certain settlement of the second service); $\mathrm{k}_0^{\mathrm{S_F S_L}}$ is the number of transfers in the sample between $\mathrm{S_F}$ and $\mathrm{S_L}$; $\mathrm{p_i}$ is a discrete value between 0 and 1 for the transfer rate; $\mathrm{M_i}$ is M, if $\mathrm{p} = \mathrm{p_i}$. There is a calculation for each ($\mathrm{S'_F}\ \mathrm{S'_L}$) pair, if $\mathrm{S'_F}$ or $\mathrm{S'_L}$ or both are present in sample items including transfer. If both are present, $\mathrm{k_0} > 0$, otherwise $\mathrm{k_0} = 0$.

4. Results and discussion

From the electronic data provided by rail operators, 427 thousand passenger trips of a weekday have been recorded. As this dataset includes transfers within rail services, no further research was required to identify OD matrix of rail passengers. Bus operators forwarded the electronically processed data of approx. 1.2 million trips on a weekday. Additional 34 thousand trips on interurban buses were registered by traditional boarding and alighting counts for the same day. As transfers within the bus sector were not included in these data, above presented methods have been used to estimate OD matrices of bus passengers (on nation and seven regional levels), as well as OD of interurban public transport passengers (i.e. including intermodal trips on rail and bus). The latter is illustrated by the number of public transport passengers (rail and bus, including transfers), see Fig. 1.

At least three (partly obvious) observations may be underlined here. First, that OD pairs (settlements) with the largest number of passengers are suburban areas of cities and towns. Second, that the capital city of Budapest is the only major urban area and the only centre of transport flows on national level. Radial structure of transport infrastructure (both road and rail) reflects the same. Third, that there are only few pairs of settlements outside the central area (Budapest area) with a significant passenger flow, linked fundamentally to the availability of reliable connections on rail (e.g. between Debrecen and Nyíregyháza in the Eastern part of Hungary) and missing transversal connection on road.

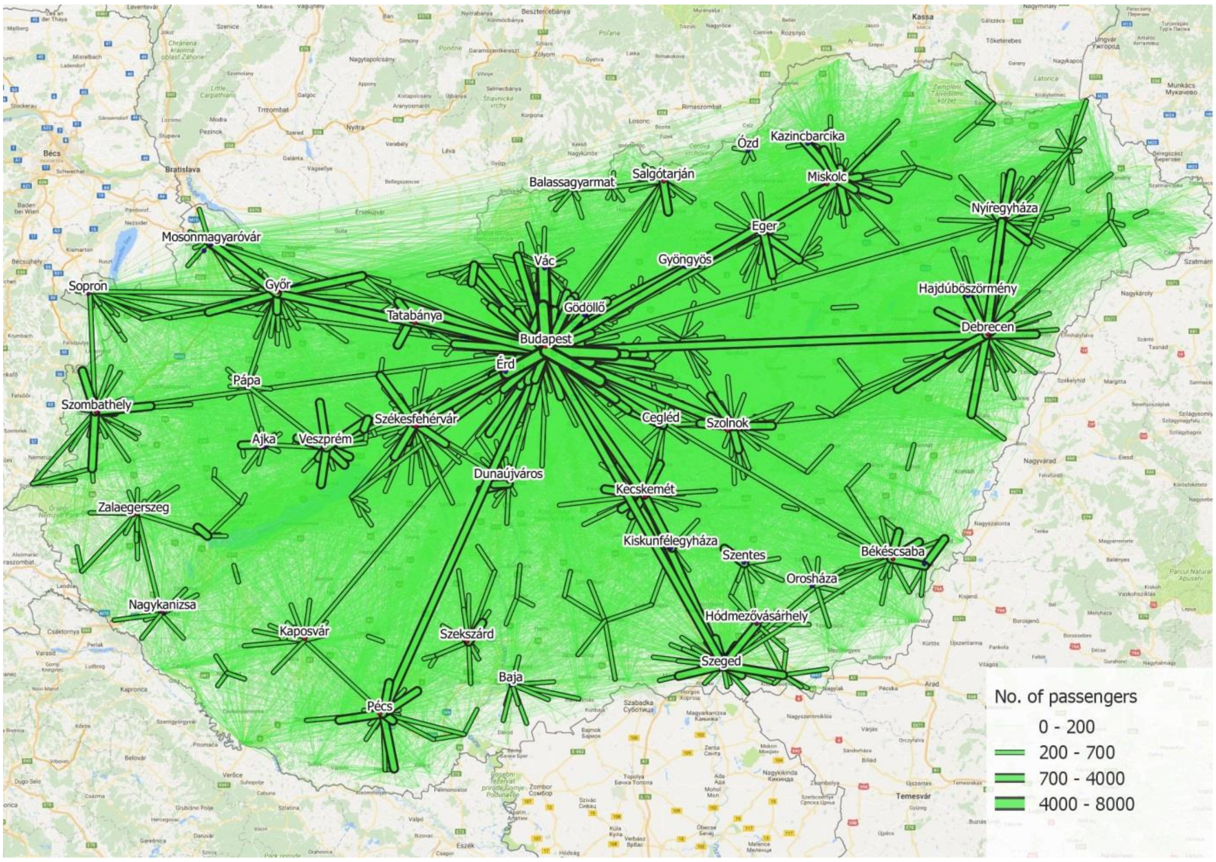

Fig. 1: Number of public transport passengers (bus and rail, incl. intermodal transfers) between origin and destination settlements in Hungary on a weekday

Data from the personal interviews is applied here to describe travel patterns of passengers in the full sample and the small but relevant group of passengers who have to make intermodal (bus↔train) transfer during their interurban trips.

4.1. General travel patterns

Student pass is the most popular choice among public transport users who need to commute or travel longer distance between different settlements (Fig. 2). The second largest group is the full fare ticket travellers (19%) together with the full fare pass holders (18%). Elderly people has 14% of share, which is lower than their share in the population. Reduced fare users are 12% and most of them are on social basis or due to their student status (Berényi and Oszter, 2017). The number of operators’ loyalty card users is lower and restricts only to rail users.

The high number of student passes matches perfectly with the proportion of trips to school (33%), while 28% of work related journeys are significantly lower than the working population rate in the society. Low current attractiveness of public transport and its fare system, as well as urban sprawl and small settlement structure in certain areas may make offering competitive public transport services currently a challenging issue. Doing errands, health and shopping trip purposes has a balanced share of 6%, but in most cases they are linked to another purpose by trip chaining as well. These multiple reasons partially appears at “other” purposes (21%) but most of the “other” classified trips are visiting friends and relatives (VFR), leisure and tourism related trips.

Share of study and work related trips (61%) goes clearly together with the share of daily trips (55%). Weekly trips add another 20% and only the remaining one quarter of the trips is done less frequently, with a split of 11% for monthly trips and 13% of less often trips (mostly health, doing errands and “other” trips, mainly with leisure and tourism purposes).

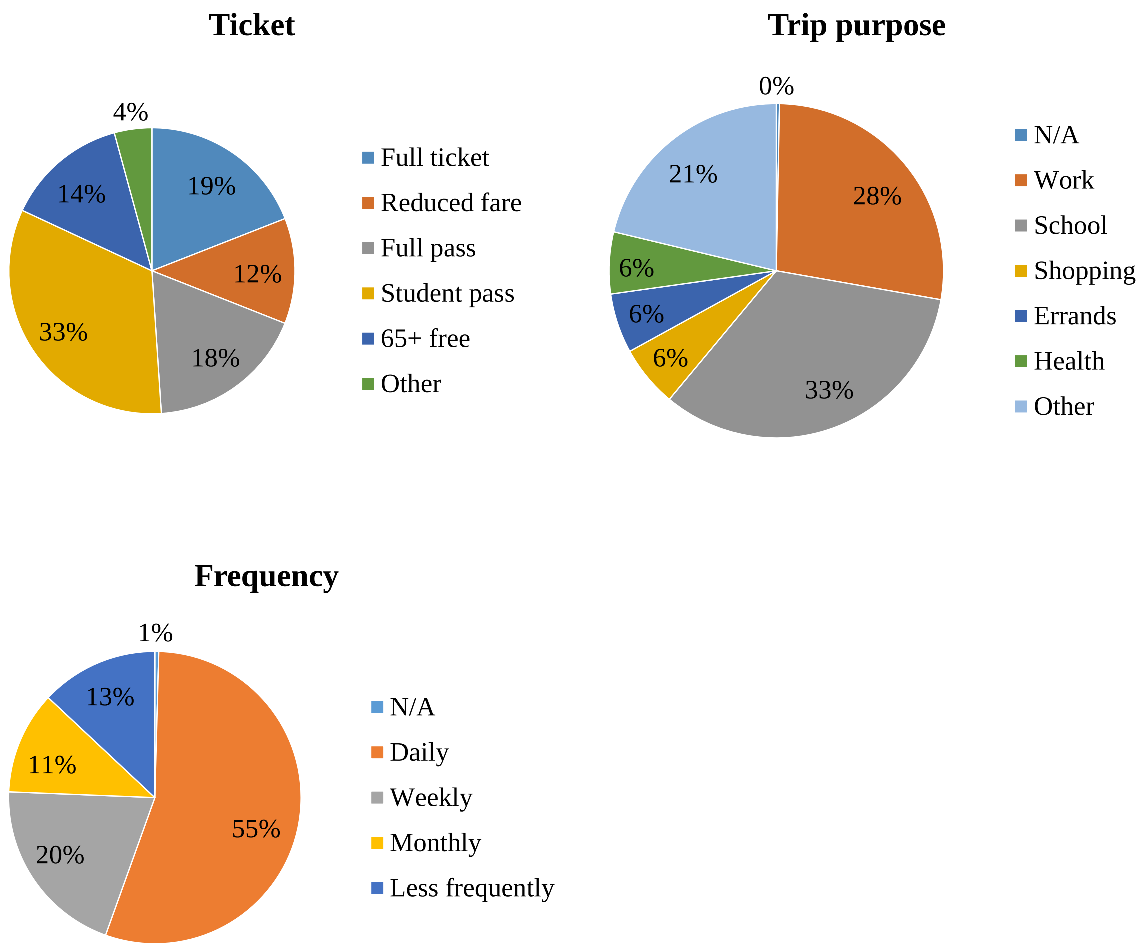

Fig. 2 Travel patterns in the full sample (N=101,409)

4.2. Intermodal transfers

On the basis of a sample of 67,676 passengers in the bus sector, including 7.9% using more than one bus services in their trip chains, estimations indicate that the rate of transfers in all trips is 1 to 5% (per region). In the full sample (101,409 answers), rate of intermodal transfers (bus↔train) is ca. 2.5% of all passengers. Here, this group of passengers is presented briefly.

Results of the personal interviews (Fig. 3) show that student pass holders constitute the largest group of intermodal transferring passengers (24%) while full fare and 65+ free travelers have higher share than regular full price monthly pass (i.e. daily utility) users. This result may indicate that the currently not integrated ticketing system is not attractive enough to buy separate monthly passes, especially for people who may have mode choice (e.g. public transport and individual modes).

Concerning trip purpose, trips to work has the highest share (29%), which shows that – in light of the percentage of full pass holders (22%) – there are passengers whose needs are better served by reduced fare tickets and, in some cases, even by full price tickets than season tickets, obviously depending on the subsidy of commuting by the employer. School trips (26%) are bit higher than the estimated share of student pass holders, which may refer to some university students who do not need to attend classes every day, and that in certain suburban areas it is better to travel with several reduced fare tickets than to purchase a student pass for a month. “Other” kind of journeys mean mostly personal reasons for VFR, leisure and sports related or trips for tourism.

As the relative majority of passengers are travelling with full or student monthly passes for work or school, it is not surprising the 45% of trips are made on a daily and an additional 21 % on a weekly basis. Monthly (16 %) and less frequent (18 %) trips distributed among VFR, doing errands and healthcare trips, while shopping is likely to add more to weekly trips purpose. In questionnaires administered to passengers on-board trains, there were extra categories of “Several times per week” (included here in “Weekly”) and “Several times per month” (“Monthly”). Results show that there are more passengers who travel several times per week due to flexible working hours, part-time work and/or distance learning (in comparison to other people who travel on a weekly basis).

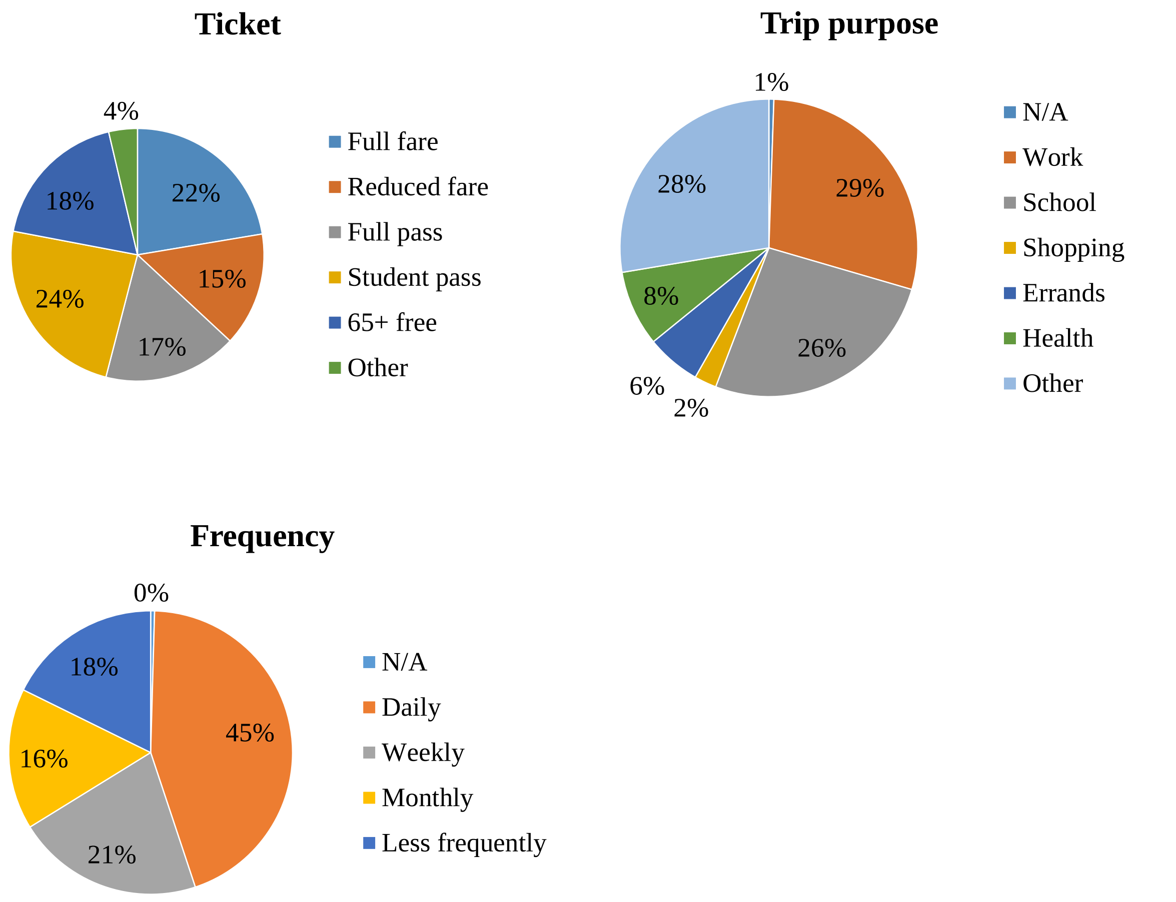

Fig. 3 Characteristics of interurban trips including intermodal (rail/bus) transfer (n=1,118)

Peculiarly, 12.1% of those who transfer from rail to bus or bus to rail have to transfer at least one more time. Although intermodal trips may reveal efficient cooperation of bus and rail lines and/or further (latent) needs for synchronizing services, full proportion of intermodal transfers among all rail (0.25%) and bus (0.1%) journeys is, for the time being, negligible.

5. Conclusion

Interurban public transport passenger OD (bus; rail; and public transport) matrices have been elaborated by the combination of traditional data collection (personal interviews and passenger counts) with electronic (e-ticketing) data. These techniques require efficient cooperation of service providers (especially for the registration of ODs of certain types of passengers), interviewers (for recording a significant number of full responses), counting staff (for recording the total number of boarding and alighting passengers at all stops) and data processing and analyzing personnel (for a reliable OD estimation).

For the illustration of outcomes by this combination of methods, main characteristics of trips, including the central role of the capital city and the consequences of a radial infrastructure development, have been briefly introduced. Some key findings of personal interviews have also been presented to identify main travel patterns of a relevant number of passengers (approx. 100 thousand, i.e. 6.4% of total). As expected, most trips are for utility purposes, however, frequencies are varied, indicating complex patterns of trips to work and school.

The method of *conversion* has been found appropriate to estimate OD on one part of the network (complementing full-scale OD information on its majority). On the one hand, having limited OD data (from responses in the sample) for certain services or lines may make the identification of temporary probabilities more difficult and the overall estimation less reliable. On the other hand, surveying passengers in major interchanges and bus terminals have revealed a relatively high number of transfers, thus rate of transfers may have been estimated – with certain limitations and assumptions – for unrevealed OD pairs as well.

In sum, this is an up-to-date and cost-efficient combination of traditional and electronic data collection methods, which may be of utmost interest for scholars, transport practitioners and decision-makers not only due to a new combination of survey and OD estimation methods but also for underlying the significance of OD matrices in transport planning in order to create seamless travel experience by an attractive and efficient public transport system. However, ongoing and upcoming developments of transport services (full introduction of e-ticketing schemes, integration of automated on-board passenger counter systems on vehicles, etc.) will replace these methods soon. In combination with computer or smart device assisted personal interviews or online questionnaires, these techniques will provide us with large scale and high level information about travel patterns and trip characteristics.

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