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Marzenna Dębowska-Mróz,
Ewa Ferensztajn-Galardos,
Renata Krajewska,
Andrzej Rogowski
Faculty of Transport and Electrical Engineering
University of Technology and Humanities in Radom

Analysis of the pedestrian traffic in transport nodes in Radom

Abstract

The efficient functioning of the transport system in each area requires that account be taken of the fact that each journey consists of a chain of elementary movements on foot or by means of transport. The construction of an effective public transport system is one of the methods to reduce traffic congestion, especially in city centres. The inter-change synchronization is the way to increase the efficiency of public transport.
The purpose of the paper is to present the results of research on the intensity of pedestrian traffic at interchanges as a function of time in the city of Radom. Pedestrian movements play an important role not only in the vicinity of transport nodes. Their production and quality also determine the assessment of these movements as one of the stages of production of combined movements. The tendency to pedestrian travel (or lack of it) also affects public and individual transport journeys. Based on the survey conducted in households, the structure of movement (size and motivations) of the inhabitants of Radom is given.

Keywords: pedestrian, pedestrian trips, public transport, transport nodes, transport behaviours, destination of pedestrian journeys
JEL Classification Codes: R41, R410

Introduction

Contemporary cities are not only urban space, but first of all the living space of the inhabitants who meet various social and economic needs. An important element of this space are transport systems, which often have to meet different expectations concerning the movements made and the accompanying problems and difficulties resulting from the occurrence of high traffic volumes [Dębowska-Mróz, Rogowski, 2013]. Entities responsible for the functioning of transport systems in cities most often focus their activities on the modernization and development of road transport infrastructure, whose aim is to ensure adequate capacity of roads and streets. Unfortunately, the consequence of these undertakings is a growing number of trips made by passenger cars, which serves the purpose of transportation most often to the person driving the vehicle and sometimes to one passenger [Dębowska-Mróz, 2017].

Administrative exclusion or significant limitation of road traffic is one of the methods of limiting traffic congestion, especially in city centres. However, this must be connected with the construction of an effective urban transport system and infrastructure enabling comfortable and safe walking and cycling journeys. Walking and cycling journeys are also part of combined journeys.

"The strategic planning process in public and rail transport, i.e., the long and medium term design of the infrastructure and the service level of a transportation network, is usually divided into the following consecutive steps: network design, line planning, and timetabling. (…) All steps of strategic planning are generally based on so-called origin destination data in the form of OD-matrices; each entry in an OD-matrix gives the number of passengers that want to travel from one point in the network to another point within a fixed time horizon. It is well known that such data have certain decencies. For instance, OD-matrices depend on the discretization used, they are highly aggregated, they give only a snapshot type of view, they are only valid when the transportation demand is fixed and does not depend on the service or price level, and it is often questionable how well the entries represent the real transportation demand" [Borndörfer, Grötschel, Pfetsch, 2010, p. 123]. Schöbel [2017] and Ceder [2011] add to this the timetable of the vehicles (vehicle scheduling). "The purpose of this work is to address the vehicle scheduling problem, while taking into account the association between the characteristics of each trip (urban, peripheral, inter-city, etc.) and the vehicle type required for the particular trip" [Ceder, 2011, Abstract].

Initially, most public transport planning models were based on one of the above-mentioned stages or sequential solutions (see [Schöbel, 2012]). One function of the criterion was also taken into account, e.g. construction cost, operating cost, maximisation of direct travel, travel times. Next, models were developed that included several stages at the same time [e.g. Schöbel, 2017; Michaelis, Schöbel, 2009; Guihaire, Hao, 2010]. Several optimisation criteria were also considered, usually as a weighted function of 'partial' criteria [e.g. Borndörfer et al., 2004; Borndörfer, Grötschel, Pfetsch, 2007]. One way to increase the efficiency of public transport is to synchronise timetables. There are two types of synchronization of public transport:

- interval synchronization;
- interchange synchronisation.

Interval synchronization concerns mainly public bus and tram transport [Varga, Tettamanti, Kulcsár, 2018; Oziomek, Rogowski, 2018] and consists in equalizing time intervals between each two consecutive means of transport running in the same direction, when there are several alternative lines between two nodes of the network.

Interchange synchronisation concerns both transport using one mode of transport as well as many different modes of transport (bus, tram, rail, metro). It is considered in many aspects depending on the criteria adopted. In its classic form, the aim of interchanges is to minimise the total waiting times for all passengers at all interchanges. In another case, it involves maximising the number of simultaneous arrivals of public transport vehicles, sometimes additionally considering the avoidance of so-called 'herds drives' of buses on common parts of transport routes. When bus and train transport is synchronised, the optimisation criterion is, on the one hand, to maximise the capacity of the railway line and, on the other hand, to minimise waiting times for changes. Among the fairly rich world literature on various forms of interchanges, we will mention here (according to the date of publication): Ceder, Tal [2001], Liu, Shen, Wang, Yang [2007], Ceder, Ne, Coriat [2009], Omar, Ibarra-Rojas, Yasmin, Rios-Solis [2012], Nair, Coffey, Pinelli, Calabrese [2013], Wu, Tang, Yu, Pan [2015], Xiao, Chien, Hu [2016], Wu, Liu, Jin [2016], Kieu, Bhaskar, Cools, Chung [2017], Liu, Ceder [2017].

It should be noted that in a large part of the publications[1] (if not in the majority), there is no verification of the models on the actual large transport network. While it seems relatively simple to build a theoretical model, it is very difficult to obtain a solution even for a medium-sized transport network. These problems are classified as NP-difficult (NP-hard). It is equally difficult to obtain reliable, complete data for real objects (this does not generally concern the problem of interval synchronization, where we optimize the existing bus transport system). Lack of accurate data is replaced by estimations. Such an example can be commissioned in [Cascetta, Papola, Marzano, Simonelli, Vitiello, 2013], where a 'quasi-dynamic' framework for estimation of origin-destination (o-d) flow from traffic counts is proposed, under the assumption that

[1] Among the publications we provide, there is information about the verification of the model (and algorithm) on a large real transport network in: [Borndörfer et al.., 2007] – they present computational results with data for the city of Potsdam in Germany, [Michaelis, Schöbel, 2009] – they optimize the local bus system in Göttingen, Germany, [Ceder, 2009] – applied in Auckland, New Zealand, [Guihaire, Hao, 2010] – present the computational experiments carried out on data from a large existing transport network without giving the network location, [Omar et al., 2012] – study the bus network of Monterrey in Mexico (the study of Monterrey bus network, Mexico [Nair et al., 2013] – this model is being implemented on the large-scale transit network of Washington, D. C, [Xiao et al., 2016] – this is a case study in which the developed model is applied to optimize the coordination of multiple bus routes connecting at a transfer station in Xi'an, China, [Kieu, 2017] – the model is validated by using observed Automatic Vehicle Location (AVL) and Automatic Fare Collection (AFC) data from two routes with transfers in South East Queensland, [Buba, Lee, 2018] – the proposed algorithm is evaluated on a well-known Mandl's Swiss network reported in the literature, [Oziomek, Rogowski, 2018] – interval synchronization for Ostrowiec Świętokrzyski in Poland.

o-d shares are constant across a reference period, whilst total flows leaving each origin vary for each sub-period within the reference period.

The transport hub – an exchange node – is a special bus stop-and-take, where transfers between different modes of transport take place as well as within one mode of transport. Its important function consisting in the convenience of performing such activities was presented in the context of the travel process, which consists of:

- getting to a bus stop;
- waiting for a means of urban transport;
- travel by public transport – change, i.e. leaving the means of transport, access to another bus stop, waiting for a means of urban transport, getting into the vehicle of public transport, traveling by public transport vehicle, and passing by public transport vehicle;
- access from the bus stop to the destination of the journey.

The organization of transfers due to a large connection with accessibility is a factor influencing the use of public transport. An important task to be carried out with a correct design of transport nodes is:

- transfer certainty;
- minimizing the time of exchange;
- maximizing the number of transportation lines;
- selection of the right frequency, depending on the time of day;
- the ability to compensate for delays;
- providing good visibility for all road users;
- ensuring appropriate conditions for the implementation of pedestrian traffic.

The main means of transport for passengers at interchanges is going on foot. However, interchanges are not only about changing the mode of transport (changing lines when there is no change in the mode of transport). In the case of journeys combined with walking, they can be the beginning or the end of a journey at the same time. In some cases, the movement of people within an interchange may not be at all related to the need to change the mode of transport. A broader perspective should, therefore, be taken into account when analysing pedestrian traffic at an interchange. It is difficult to find works that deal directly only with pedestrian traffic at interchanges and to analyse their functioning from this perspective. The interchange is usually analysed as an (important) element of the transport system in the problems of interchange synchronisation.

The analysis of modelling and 'measuring' of pedestrian behaviour in transport systems in the literature is considered in many aspects.

Chamier-Gliszczyński [2015] refers to issues related to modelling of travel structure for the needs of urban logistics by defining a travel structure model in urban areas. It analyses, on the basis of the example of Szczecin, the structure of travel, including pedestrian travel. In [Chamier-Gliszczyński, Bohdal, 2016] the process of shaping the transport behaviour of urban users was analysed. The analysed transport behaviours were related to the selected urban area where the research on the structure of urban journeys was carried out. These studies analyse walking and non-walking journeys. Individual and collective journeys by means of transport and multimodal journeys were analysed in detail.

The work [Sierpiński, Staniek, Celiński, Czech, Barcik, 2015] discusses the issue of movement modelling, and in particular the modal split. The article summarizes many definitions of pedestrian travel used in practice. The results of research on the identification of the concept of pedestrian travel among travellers are also presented. The findings of the research determining the permissible distance to the nearest public transport stop, which has a direct impact on the analysis of transport accessibility of the selected area, are presented.

Wachowiak [2018] analyses the potential of creating a polycentric system of multimodal interchanges based on the existing railway stations (district stations) of Poznan. Using in-depth interviews, passengers' needs and destinations were identified.

Pecenik [2017] analyses the interchange in Warsaw at the intersection of Marszałkowska Street and Jerozolimskie Avenue, called Dmowskiego Roundabout. He measured the times of interchanges at the transfer node.

In their work, Numov and Samchuk [2017] present a library of classes implemented in Python, which could be used for computer simulations of public transfer nodes. The proposed software allows researchers to change technological parameters during simulation procedures and makes possible automation of simulation experiments in the field of passengers' transportation.

Nishiuchia, Todorokib and Kishib [2015] propose a method of evaluating transfer nodes based on smart card data with the objective of making a contribution to public transportation restructuring in regional cities. The study seeks to better comprehend the use of public transportation systems (trams and buses) in central Kochi City in Japan based on the transportation mode transfers recorded on user Smart Cards.

In [Xi, Son, 2012] a microscopic two-level simulation modelling framework is proposed to analyse both decision-making processes at a crosswalk as well as physical interactions among pedestrians when they cross a street. An extension on coupling the proposed pedestrian model with a transportation simulation model is also briefly discussed.

Pedestrian movements are a consequence of several complex and stochastic facts. In their paper, Rahman, Ghani, Kamil, Mustafa and Chowdhury [2013], a queuing-based analytical model is developed as a function of relevant determinants and functional factors to predict the travel time on pedestrian facilities.

Serge, Hoogendoorn and Bovy [2005] present a dynamic mixed discrete-continuous choice approach to modelling pedestrian travel and activity choice behaviour in public facilities. The approach views revealed behaviour as a manifestation of pedestrians' preferences by assuming that pedestrians choose the alternative that maximizes expected (subjective) utility, while taking into account the uncertainty in expected traffic conditions.

The paper of Iacono, Krizek and El-Geneidy [2010] "explores the issues related to the development of accessibility measures for non-motorized modes, namely bicycling and walking. We note that difficulties in calculating accessibility measures arise primarily from problems with data quality, the zonal structure of transportation planning models, and the adequacy of models and travel networks for describing and predicting travel by non-motorized modes".

The work of Yamamoto, Takamura and Morikawa [2018] includes how "a nested logit model of mode and walk route choice behaviour in a downtown area is developed. (…) Dataset is obtained by using mobile phones with GPS functions to track the trajectories in a downtown area at Nagoya, Japan."

The article presents transport nodes in Radom that are interchange nodes, which is the area of our interest. They concern rail transport, public bus and private bus transport (the so-called BUS) and pedestrian travel in the case of Radom. We were interested in the intensity of pedestrian traffic as a function of time and learning about preferences in terms of making decisions on the choice of the way of moving residents within the city, including the indication of factors influencing the choice between individual and collective public transport. Pedestrian traffic plays a role not only in the vicinity of transport hubs. Their implementation and quality also determine the assessment of these movements as one of the stages of implementation of combined movements. The tendency to travel on foot (or lack of it) also has an impact on public and private transport travel. The structure of movement (size and motivations) of the inhabitants of Radom is presented on the basis of a survey conducted in households. The research was conducted in June and July 2014. Source statistical data from the survey are included in Ciszewski, Dębowska-Mróz, Ferensztajn-Galardos, Grad, Krajewska, Łukasik, Rogowski, Wojciechowski [2014].

1. Pedestrian travel of Radom's residents based on surveys in households

A survey was conducted among households in Radom under a project [Ciszewski et al., 2014]. It aimed at obtaining information on the mobility of the inhabitants of Radom and the surrounding area. Respondents indicated all journeys made on the working day preceding the day of the survey, in the so-called 'Travel diary'. The study involved people over 12 years of age.

Surveys were conducted in 1,747 households in Radom (out of 70,615 existing), receiving answers from 2,913 respondents (1,635 women, 1,278 men). Household drawing was proportionally layered (a layer was made up of households with 1, 2, 3, 4, 5+ household members). At the age of 13, there were (according to the PESEL database) 186,987 people in Radom (99,822 women, 87,005 men). The surveyed households were inhabited by a total of 5,187 people, of which 46.53% were men, and 53.47% were women.

A resident of Radom most often traveled by car as the driver, on foot and by public transport. Based on the surveys, it was estimated that the average mobility of Radom residents aged over 12 was at the level of 2,782 trips made by one person per day and the total number of trips eqalled 520.2 thousand. In the case of pedestrian travel, these values are respectively 0.771 and 144.1 thousand (Table 1).

Over 63% of Radom residents declared that they had travelled on foot (in the group of 13–17 years of age, about 80%). However, from the actual number of trips given, it appears that only 32.3% of such trips took place.[2] A definitely higher percentage of women performs walking tours than men (a difference of almost 10 pp), in each age category, except for categories of 13–17 years of age, where men are clearly predominant (16 pp difference) and only in this group over 50% of residents take walking tours on a given working day date. The average daily number of walking trips made by an inhabitant of Radom is 0.771 (women: 0.898 and men: 0.624); women travel 90,000 daily and men 54 thousand.[3] The survey included complex journeys, i.e. carried out with at least two means of transport.[4] In the case of pedestrians, the percentage of complex trips amounted to 31.5% (32.04% of women and 30.64% for men, which gives 29 thousand and 19.5 thousand of trips made, which included a walking trip). It is worth noting that the lowest percentage was among men aged 13–17, when at the same time in this age group there was the highest percentage of hiking trips.

Table 1. Percentage of respondents (%) taking a walking trip based on actual travel

	Women					Men					Women + Men				
	13–17	18–44	45–59	60+	Total	13–17	18–44	45–59	60+	Total	13–17	18–44	45–59	60+	Total
1	45.31	32.68	34.02	45.17	36.66	61.43	21.55	21.03	36.88	26.78	53.73	27.47	28.70	41.95	32.33
2	1.188	0.748	0.816	1.109	0.898	1.529	0.505	0.456	0.810	0.624	1.363	0.624	0.650	0.992	0.771
3	5743	30432	18852	34760	89787	7802	21263	9000	16255	54320	13545	51695	27852	51015	144107
4	21.05	31.64	45.31	27.02	32.04	11.21	35.59	41.13	27.70	30.64	15.39	33.27	43.96	27.23	31.52
5	79.69	66.01	68.29	75.36	69.46	82.86	50.97	50.92	68.06	56.23	81.34	58.97	61.18	72.53	63.66

1 – percentage of Radom's residents who travel on foot on the basis of real journeys [%]
2 – average daily number of pedestrian trips in Radom [number of trips/person]
3 – estimated daily number of pedestrian trips
4 – percentage of pedestrians as part of a combined journey (at least two means of transport) on pedestrian trips
5 – a declarative percentage of Radom's residents who travel on foot

Source: own material.

The surveys analysed the motivations of the inhabitants of Radom. Eight source/destination motivations were distinguished:

1. House: place of residence;
2. Work: place of starting work;
3. Education: schools, colleges, place of courses, training;
4. Shopping and services: to the kiosk, shop, shopping centre;

[2] This may be due to the difficulty of what should be considered a walking trip. It seems that we travel almost every day, but when the purpose of such travel and the start and end time should be changed, there is a change of opinion.

[3] The ratio of the average daily number of trips made by women and men respectively is 1.44 and the number of trips is 1.65 – this is due to the fact that there are nearly 13,000 more women than men.

[4] Journey on foot treated as a means of transport. The trip is one journey in the statistics, although when determining the number of journeys, the given means of transport was included in the journey for each of the used means of transport.

5. Recreation and entertainment: sports, cinema and restaurants;
6. Business matters: all trips made as part of work;
7. Offices, hospitals, clinics, banks, courts: performed not as part of work;
8. Other purposes: e.g. travel to visit a person, taking a person to a place.

The tables below present the average daily number of walking trips according to the travel source (Table 2) and destination (Table 3) and in the source-to-target destnations (Tables 4 and 5, only those trips for which the average number of trips were not less than 0.1).

Table 2. Average daily number of journeys of the inhabitants of Radom and the share of the travel (%) by the beginning of the journey in pedestrian trips based on real travel

The beginning of the journey	Average number of journeys	Share (%)	Average number of journeys	Share (%)	Average number of journeys	Share (%)	Average number of journeys	Share (%)
	Women 13–17 years		Men 13–17 years		W+M 13–17 years		W 13+ years	
1	0.609	51.32	0.757	49.53	0.685	50.29	0.432	48.14
2	0.000	0.00	0.000	0.00	0.000	0.00	0.064	7.15
3	0.250	21.05	0.414	27.10	0.334	24.54	0.028	3.12
4	0.109	9.21	0.143	9.35	0.127	9.29	0.180	20.01
5	0.156	13.16	0.129	8.41	0.142	10.42	0.051	5.71
6	0.000	0.00	0.000	0.00	0.000	0.00	0.005	0.60
7	0.000	0.00	0.000	0.00	0.000	0.00	0.045	5.03
8	0.063	5.26	0.086	5.61	0.074	5.46	0.092	10.23
Total	1.188	100	1.529	100	1.363	100	0.898	100
	Women 18–44 years		Men 18–44 years		W+M 18–44 years		M 13+ years	
1	0.350	46.85	0.236	46.76	0.292	46.82	0.299	47.92
2	0.088	11.71	0.059	11.76	0.073	11.73	0.053	8.53
3	0.039	5.24	0.033	6.47	0.036	5.75	0.041	6.56
4	0.124	16.61	0.056	11.18	0.090	14.37	0.092	14.75
5	0.065	8.74	0.067	13.24	0.066	10.59	0.057	9.14
6	0.005	0.70	0.001	0.29	0.003	0.53	0.002	0.26
7	0.016	2.10	0.007	1.47	0.011	1.84	0.023	3.61
8	0.060	8.04	0.045	8.82	0.052	8.36	0.058	9.24
Total	0.748	100	0.505	100	0.624	100	0.624	100
	Women 45–59 years		Men 45–59 years		W+M 45–59 years		W+M 13+ years	
1	0.395	48.44	0.213	46.77	0.311	47.90	0.370	48.06
2	0.107	13.13	0.081	17.74	0.095	14.62	0.059	7.67
3	0.000	0.00	0.004	0.81	0.002	0.26	0.034	4.42
4	0.166	20.31	0.055	12.10	0.115	17.66	0.139	18.03
5	0.028	3.44	0.033	7.26	0.030	4.67	0.054	7.00
6	0.008	0.94	0.000	0.00	0.004	0.63	0.004	0.47
7	0.043	5.31	0.029	6.45	0.037	5.68	0.035	4.50
8	0.069	8.44	0.040	8.87	0.056	8.58	0.076	9.86
Total	0.816	100	0.456	100	0.650	100	0.771	100

The beginning of the journey	Average number of journeys	Share (%)	Average number of journeys	Share (%)	Average number of journeys	Share (%)	Average number of journeys	Share (%)
	Women 60+ years		Men 60+ years		W+M 60+ years			
1	0.539	48.58	0.399	49.30	0.484	48.81		
2	0.012	1.09	0.027	3.29	0.018	1.79		
3	0.000	0.00	0.000	0.00	0.000	0.00		
4	0.273	24.62	0.190	23.47	0.241	24.25		
5	0.034	3.05	0.042	5.16	0.037	3.72		
6	0.005	0.44	0.004	0.47	0.004	0.45		
7	0.092	8.28	0.053	6.57	0.077	7.74		
8	0.155	13.94	0.095	11.74	0.131	13.24		
Total	1.109	100	0.810	100	0.992	100		

Source: own material.

A vast majority of walking trips performed by the residents of Radom began at the place of residence (1) 48.06%, and a very large share (over 18%) from the place of shopping and to a small extent the share depended on sex (without distinguishing the age groups). Significant differences occur between age groups (mostly understandable because, for example, young people generally do not travel to work and adults to schools).

It is also possible to analyse the destination of the inhabitants of Radom in various age groups based on the research (Table 3).

Table 3. Average daily number of trips of the inhabitants of Radom and their share in pedestrian travel (%) by destination based on real travel

Destination of journeys	Average number of journeys	Share (%)	Average number of journeys	Share (%)	Average number of journeys	Share (%)	Average number of journeys	Share (%)
	Women 13–17 years		Women 18–44 years		Women 45–59 years		Women 60+ years	
1	0.516	43.42	0.324	43.36	0.352	43.13	0.517	46.62
2	0.000	0.00	0.089	11.89	0.094	11.56	0.017	1.53
3	0.234	19.74	0.033	4.37	0.000	0.00	0.000	0.00
4	0.141	11.84	0.144	19.23	0.204	25.00	0.280	25.27
5	0.234	19.74	0.072	9.62	0.031	3.75	0.031	2.83
6	0.000	0.00	0.004	0.52	0.008	0.94	0.005	0.44
7	0.000	0.00	0.014	1.92	0.051	6.25	0.101	9.15
8	0.063	5.26	0.068	9.09	0.077	9.38	0.157	14.16
Total	1.188	100	0.748	100	0.816	100	1.109	100
	Men 13–17 years		Men 18–44 years		Men 45–59 years		Men 60+ years	
1	0.757	49.53	0.245	48.53	0.224	49.19	0.369	45.54
2	0.000	0.00	0.058	11.47	0.077	16.94	0.030	3.76
3	0.386	25.23	0.033	6.47	0.004	0.81	0.000	0.00
4	0.157	10.28	0.056	11.18	0.051	11.29	0.217	26.76
5	0.143	9.35	0.059	11.76	0.029	6.45	0.049	6.10

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Destination of journeys	Average number of journeys	Share (%)	Average number of journeys	Share (%)	Average number of journeys	Share (%)	Average number of journeys	Share (%)
6	0.000	0.00	0.003	0.59	0.004	0.81	0.004	0.47
7	0.000	0.00	0.007	1.47	0.026	5.65	0.049	6.10
8	0.086	5.61	0.043	8.53	0.040	8.87	0.091	11.27
Total	1.529	100	0.505	100	0.456	100	0.810	100
	W+M 13–17 years		W+M 18–44 years		W+M 45–59 years		W+M 60+ years	
1	0.640	46.94	0.284	45.48	0.293	45.09	0.459	46.28
2	0.000	0.00	0.073	11.72	0.086	13.30	0.022	2.24
3	0.312	22.90	0.033	5.23	0.002	0.26	0.000	0.00
4	0.149	10.94	0.099	15.92	0.134	20.57	0.255	25.75
5	0.187	13.75	0.066	10.50	0.030	4.62	0.038	3.87
6	0.000	0.00	0.003	0.55	0.006	0.90	0.004	0.45
7	0.000	0.00	0.011	1.74	0.039	6.05	0.081	8.18
8	0.074	5.46	0.055	8.86	0.060	9.21	0.131	13.24
Total	1.363	100	0.624	100	0.650	100	0.992	100
	W 13+ years		M 13+ years		W+M 13+ years			
1	0.400	44.58	0.299	47.89	0.353	45.83		
2	0.063	7.05	0.053	8.42	0.058	7.56		
3	0.025	2.74	0.039	6.29	0.031	4.08		
4	0.200	22.31	0.098	15.73	0.153	19.83		
5	0.058	6.41	0.055	8.84	0.056	7.32		
6	0.005	0.54	0.003	0.50	0.004	0.53		
7	0.049	5.51	0.021	3.34	0.036	4.69		
8	0.098	10.87	0.056	8.99	0.078	10.16		
Total	0.898	100	0.624	100	0.771	100		

Source: own material.

The main purpose of the journeys of pedestrian residents of Radom on the weekday preceding the survey was home – 45.83%, followed by going shopping 19.83% and other purposes (as a category) – 10.16%.

Selected directions and their share in the number of walking trips carried out by women are included in Table 4. The above-mentioned 8 destinations in each age group cover over 60% of completed pedestrian trips. In the 13–17 age group, it is close to 95%, whereas in the home – education/shopping/recreation and return directions, it is over 84% of the journeys. In the other age groups, except for 60+, two house-shopping and shopping–house directions (out of 64 defined) have a significant share of approximately 30%. In the case of the 60+ age group, these are four home-shopping destinations, house-other, shopping-home, and other-home for over 72% of trips.

In the case of men (Table 5) only in the age group of 13–17 and 60+ there was a situation that the average daily number of walking trips was no less than 0.1 trips. In the group of 13–17, there are eight accounts for almost 99% of journeys, and six for an average of not less than

0.1, almost 88% (these are the same destinations for women as specified in Table 4). Almost an identical situation occurs in this group without the distinction of sex (for other age groups the situation is similar to that in the respective groups of women). In the 60+ group, the corresponding values are 78%, 2 destinations, 47%. Note that in the group of 13–17 among women, pedestrian travel was carried out only for eleven destinations and for men for nine destinations (Table 6).

Table 4. Average daily number of walking trips and the share of (%) in direct trips carried out by women in individual age groups based on real journeys*

Trips		13–17 years		18–44 years		45–59 years		60+ years		13+ years	
		x	y (%)	x	y (%)	x	y (%)	x	y (%)	x	y (%)
1–3	Home – Education	0.234	19.7	0.030	4.0	0.000	0.0	0.000	0.0	0.024	2.6
1–4	Home – Shopping	0.125	10.5	0.102	13.6	0.166	20.3	0.251	22.7	0.165	18.3
1–5	Home – Recreation	0.188	15.8	0.064	8.6	0.028	3.4	0.029	2.6	0.051	5.6
3–1	Education – Home	0.203	17.1	0.025	3.3	0.000	0.0	0.000	0.0	0.020	2.2
4–1	Shopping – Home	0.094	7.9	0.106	14.2	0.145	17.8	0.254	22.9	0.161	17.9
5–1	Recreaction – Home	0.156	13.2	0.063	8.4	0.026	3.1	0.034	3.1	0.050	5.5
1–8	Home – Other	0.063	5.3	0.060	8.0	0.066	8.1	0.152	13.7	0.091	10.1
8–1	Other – Home	0.063	5.3	0.047	6.3	0.064	7.8	0.145	13.1	0.082	9.2

x – average daily number of trips, y – travel share in trips in a given age group
* Only trips in which even in one group the average daily number of trips is not less than 0.1.
Source: own material.

Table 5. Average daily number of pedestrian trips and share (%) in direct trips carried out by a) men, b) men and women in individual age groups based on real journeys*

Trips		M 13–17 years		M 60+ years		W+M 13–17 years		W+M 45–59 years		W+M 60+ years		W+M 13+ years	
		x	y (%)	x	y (%)	x	y (%)	x	y (%)	x	y (%)	x	y (%)
1–3	Home – Education	0.386	25.2	0.000	0.0	0.312	22.9	0.002	0.3	0.000	0.0	0.031	3.4
1–4	Home – Shopping	0.143	9.3	0.198	24.4	0.134	9.8	0.111	17.1	0.230	23.2	0.130	14.5
1–5	Home – Recreation	0.143	9.3	0.046	5.6	0.165	12.1	0.029	4.4	0.035	3.6	0.051	5.7
3–1	Education – Home	0.400	26.2	0.000	0.0	0.304	22.3	0.002	0.3	0.000	0.0	0.028	3.1
4–1	Shopping – Home	0.143	9.3	0.183	22.5	0.119	8.7	0.102	15.7	0.226	22.8	0.127	14.1
5–1	Recreation– Home	0.129	8.4	0.042	5.2	0.142	10.4	0.027	4.2	0.037	3.7	0.052	5.8
1–8	Home – Other	0.086	5.6	0.084	10.3	0.074	5.5	0.053	8.1	0.125	12.6	0.072	8.0
8–1	Other – Home	0.086	5.6	0.084	10.3	0.074	5.5	0.053	8.2	0.121	12.2	0.070	7.8

x – average daily number of a resident's travel in a given age group, y – travel share in trips in a given age group (%)
* Only trips on which, in one group (separately for men and men and women), the average daily number of trips is not less than 0.1. In the non-existent groups there were no trips that met this condition.
Source: own material.

Men not only less often used pedestrian routes, but also the number of motivations for traveling (source-destination) is much smaller than for women (Table 6). Note that out of 64 motivations,[5] the respondents indicated 47 motivations – women 43, men 31; so men indicated three motivations that did not occur among women. These are: work-work, recreation-other, offices/hospital-business matters.

Table 6. Number of source–destination trips in pedestrian trips in particular age groups, including gender

Women					Men					Women + Men				
13–17	18–44	45–59	60+	Total	13–17	18–44	45–59	60+	Total	13–17	18–44	45–59	60+	Total
11	39	26	22	44	9	22	17	19	31	11	43	32	26	47

Source: own material.

2. Analysis of people's movements in transport nodes on the example of Radom

Transportation behaviours of city public transport users are conditioned by many factors, including spatial development, or the distance between places of business activity, administrative cultural and entertainment, sports and recreation activities and other important places of social and living needs. These factors constitute the source of transport needs realized in the form of displacements carried out at different times, frequencies and at different distances. Urban dwellers can produce their movements in a variety of ways, i.e. on foot, using individual means of transport or public transport. Different types of travel within urban travel depend on many factors, such as: demographic aspects, urban infrastructure, and mobility of residents.

Analysing the functioning of public transport in Radom, both regional and long-distance, the focus was on the exchange of travellers in relation to people using different modes of transport. The obtained measurement material has been subjected to standard processing. Its essential element was the basic statistical analysis and visualization of its results. The results of the measurements were processed to a form enabling their further possible treatment and presented in the form of tables and histograms.

The following spaces in the city are considered to be interchange points in Radom: near the PKP and PKS stations (Figures 1 and 2), BUS stopping places that realize transport needs in terms of displacements of the residents of the Radom Function Area and guests arriving to this functional area.

[5] In this type (x)–(x); from this type of destination, there were the following: work-work, education-education, recreation-recreation and business matters-business matters.

Figure 1. Location of transport generators near the railway and bus stations

Source: http://www.mzdik.pl/index.php?id=194

Figure 2. A list of feasible exchanges around the PKP and PKS stations

Source: http://www.mzdik.pl/index.php?id=194

The proposed research procedure aims at learning the preferences in the decision-making as to how to move around the city, including the factors affecting the choice between individual transport and collective public transport as part of the analysis of pedestrian traffic in transport hubs in Radom.

The implementation of the study was divided into three stages. The methodological basis of the study was developed as part of the first stage, including the research problem and purpose of the study, its scope was specified, methods of collecting information were selected, and areas for observing the area where the intensity of pedestrian traffic was planned. Implementation of the research – as the second stage, included: organizational and technical preparation of the study, collection of information, formal and substantive verification of information, coding of information. The study was carried out in three traffic generators – at the PKP station, at the bus station and at bus stops where private carriers stop. The analysis and interpretation of the findings of the study is a range of the third stage of the research, in which the methods allowing multidimensional analysis of the collected data were used, assuming an integrated approach to the analysis of transportation behaviours of city dwellers. Integration of the approach is understood in this case as the simultaneous application of different methods of analysis of the collected research material, including multidimensional data classification and analysis methods, which also means not only analysis of transportation behaviour of urban residents, but also identification of factors deciding about making a choice between transport means within a city using individual means of transport or means of collective passenger transport.

Table 7 presents the data on the total pedestrian traffic at platforms 1, 2, 3 of the PKP station, at the PKS bus stations and at the bus stops of the private carriers in Radom in the context of maximum values in relation to the traffic peak both morning and afternoon as well as the time between traffic peaks. Observations connected with the analysis of the exchange of travellers were carried out on June 11 from 6:00 am to 10:00 am, 11:00 am – 1:00 pm, 2:00 pm – 7:00 pm as a measurement of pedestrian traffic near the designated measurement points.

The maximum pedestrian traffic at platforms 1, 2, 3 of the PKP railway station in Radom (Table 7) occurs during morning rush hours between 7.15 am and 8.15 am and amounts to 442 people, in the afternoon rush hours between 3.30 pm and 4.30 pm there were 343 persons and in the hours between traffic peaks, i.e. between 11.00 am and 12.00, 188 people. In the case of pedestrian traffic at the bus station in Radom (Table 7), to the hours of the so-called traffic peak one can include respectively morning – the time interval between 6.30 am and 7.30 am in which the pedestrian traffic was accounted for 282 people, afternoons – the time interval between 4.30 pm and 5.30 pm when there were 283 persons and between 11.45 am and 12.45 pm when the pedestrian traffic rate was 210 people. On the other hand, at the BUS stops of private carriers (Table 7), the morning traffic peak was between 6.30 and 7.30, similarly to the PKS station, however, the number of people moving at the BUS stops of private carriers was lower by 116 persons than the number of people moving at the PKS station and was at the level of 166 people. The afternoon traffic peak at these BUS stops, where 140 people were recorded, starts at 3.15 pm and lasts until 4.15 pm. In between the hours of traffic, occurring in the same time as at the platforms of the PKP station from 11.00 am to hours 12.00, there were 78 people.

Table 7. List of the total pedestrian traffic at platforms 1, 2, 3 of the PKP station, at the PKS bus stations and at the bus stops of the private carriers in Radom together with the indication of maximum values in the morning rush hours, afternoon rush hours and hours between traffic peaks

Time	The number of pedestrians at platforms 1, 2, 3 of the PKP station	The number of pedestrians at the PKS bus station	The number of pedestrians at the bus stops of the private carriers
6:00–7:00	180	152	107
6:15–7:15	30	187	147
6:30–7:30	230	282 Max	166 Max
6:45–7:45	275	252	136
7:00–8:00	433	238	121
7:15–8:15	442 Max	234	107
7:30–8:30	299	153	86
7:45–8:45	312	195	109
8:00–9:00	176	200	133
8:15–9:15	258	208	97
8:30–9:30	221	183	94
8:45–9:45	198	148	93
9:00–10:00	227	164	86
11:00–12:00	188 Max	185	78 Max
11:15–12:15	132	177	67
11:30–12:30	51	184	59
11:45–12:45	73	210 Max	76
12:00–13:00	93	199	66
14:00–15:00	202	223	103
14:15–15:15	204	236	97
14:30–15:30	236	285	89
14:45–15:45	301	280	109
15:00–16:00	288	286	135
15:15–16:15	296	245	140 Max
15:30–16:30	343 Max	210	134
15:45–16:45	205	239	113
16:00–17:00	260	235	85
16:15–17:15	276	221	67
16:30–17:30	182	283 Max	48
16:45–17:45	165	227	65
17:00–18:00	134	202	61
17:15–18:15	111	188	80
17:30–18:30	257	172	76
17:45–18:45	222	188	50
18:00–19:00	205	212	44

Source: own material.

The relatively high pedestrian traffic at the PKP railway station platforms (Table 7) was recorded in the morning between 7.00 and 8.00 o'clock, respectively, however, it should be noted that from 6.30 to 8.00 the intensity was on the rise. In the afternoon hours, the smallest pedestrian traffic was on the platforms of the PKP station between 11.30 and 13.00 – when usually both working people and pupils commuting with this mode of transport to work or school, respectively, are staying at the destination of their journey. Another noticeable increase in pedestrian traffic was recorded between 2.00 pm and 3.45 pm, which may be related to the end of work in plants operating in a three-shift system, or public administration offices and schools – these displacements usually concern people who, immediately after work or classes, return home. As a rule, from 3.00 pm pedestrian traffic at the platforms of the PKP railway station – outside the afternoon traffic peak – shows a downward trend until 6.00 pm. In addition, it should be noted that in the morning the smallest traffic at the platforms of the PKP railway station, amounting to 30 people, starts at 6.15 and lasts until 7.15; in the early afternoon hours, i.e. between 11.30 and 12.30 around 50 people moved, while in the afternoon hours, i.e. between 5.15 pm and 6.15 pm – 111 people. Significantly less pedestrian traffic was recorded at the PKS station (Table 7) compared to platforms 1, 2 and 3 of the PKP station. However, in the morning, between 6.00 am and 7.30 am, this intensity was higher than at the platforms of the PKP railway station. Moreover, in the afternoon hours there was no such a significant decrease – the number of people moving at the bus station was at the level of about 200 people between 11.30 and 1.00 pm. In addition, it is worth noting that in any period of time – either in the morning hours or in the afternoon – the number of people moving at the bus station did not fall below 100 persons, as was the case with pedestrian traffic at selected platforms of the PKP station. This intensity was relatively lower, but more even, there were not as big differences as to the specified time intervals.

The smallest pedestrian traffic was recorded at the BUS stops of private carriers (Table 7). Most people travel there between 6.15 am and 7.45 am and between 3.00 pm and 4.30 pm, This intensity did not exceed 100 people in most other specified time periods and the smallest pedestrian traffic at these stops was between 11.00 and 1.00 pm.

The distribution of pedestrian traffic at the PKP and PKS stations in Radom and at the bus stops of private carriers located in the vicinity of the PKP and PKS stations in Radom has been presented in Figures 3, 4 and 5, respectively, broken down by persons entering and leaving these places from 6.00 am to 6.45 pm.

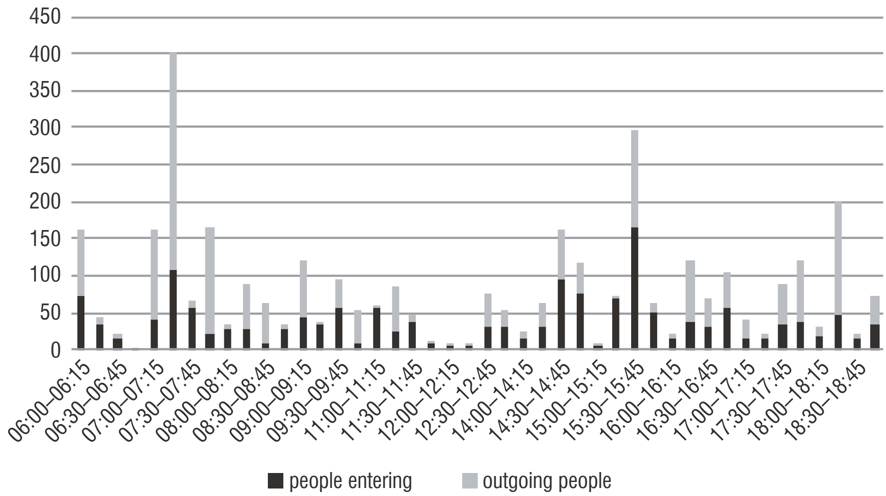
The distribution of intensity (Figures 3, 4, 5) in the context of two categories of passengers, i.e. persons entering and outgoing, can be said to be uneven and not only in relation to traffic generators, but also to time intervals. Passengers both entering and outgoing use collective transport in a variety of ways depending on their preferences, as well as the availability of individual modes of transport within their timetables.

Most people came out of the PKP train station between 7.00–7.15 and 7.30–7.45, respectively, which is undoubtedly connected with the schedule of train arrivals constituting a means of transport for them as well as at 3.30 pm to 3.45 pm and between 6.00 pm and

6.15 pm. And when it comes to the people entering the station is worth noting the time interval between 3.30 pm and 3.45 pm. In addition, generally between 11.30 am and 12.15 the pedestrian traffic was low.

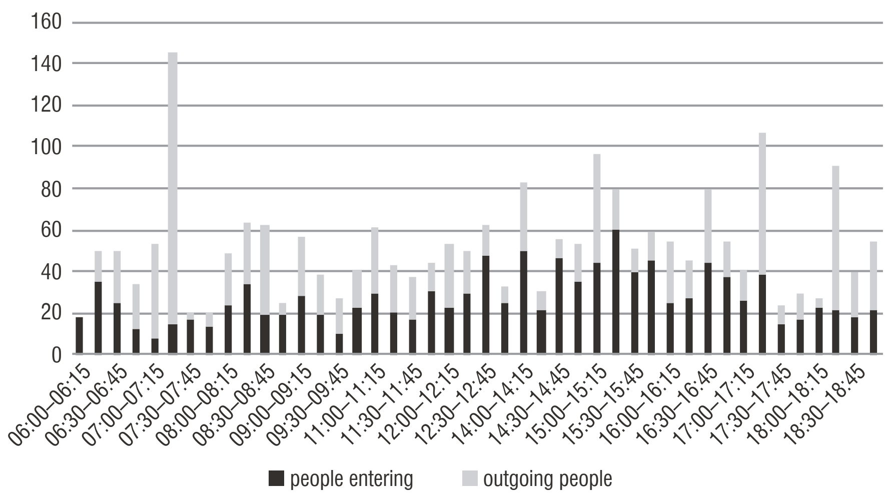
As part of depicting the distribution of pedestrian traffic at the bus station in Radom, only people entering the station were included, the most of which appeared between the hours 12.30 and 5.15 pm.

Figure 3. The distribution of pedestrian traffic at the PKP railway station in Radom



Source: own material.

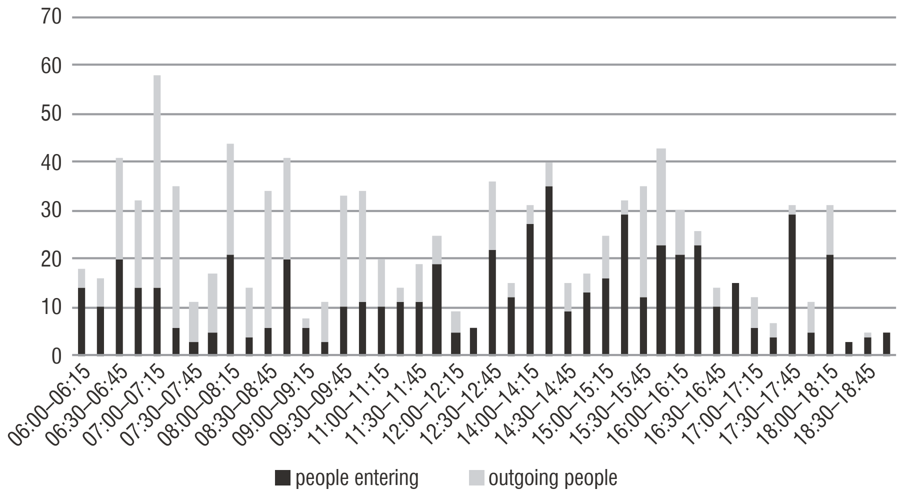
Figure 4. The distribution of pedestrian traffic at the PKS station in Radom



Source: own material.

In the case of pedestrian traffic at bus stops near the railway and bus stations in Radom, it can be stated that most of the outgoing people were people travelling between 6.30–7.45, 8.00–8.45, as well as 3.30 pm–3.45 pm, and those entering – people making their journeys between the hours: 6.30–7.15, 8.00–8.15, 8.30–8.45, 9.30–11.45, 12.30 pm–4.45 pm and 5.30 pm–5.45 pm, as well as 6.00 pm–6.15 pm.

Figure 5. The distribution of pedestrian traffic flow at BUS stops near the railway and bus stations in Radom



Source: own material.

Table 10. Total number of the passenger exchange observed at the PKS station

Time	Operator	Direction	The numer of people	The number of people getting off
06:02		Lodz	30 people left	
06:10	BUS of private carrier	Warsaw	35 people left	
06:31	Polish BUS	Warsaw	25 people left	
06:45	VIKI	Warsaw	22 people left	
06:25		Bialobrzegi	4 people left	
06:23	Suburban line	Jastrzebia		1
06:30		Tczow		1
06:40		Zwolen	6 people got in	
06:42		Gozd	2 people got in	
06:46		from Tczow		10
06:49		Gozd		12
06:49		Dzierzkowek		20
07:10	PKS	Warsaw	10 people got in	
07:13		Lublin	20 people got in	
07:30		Warsaw	5 people got in	
07:40		Jedlinsk	2 people got in	
08:05		Gdansk	20 people got in	2
08:48		Lodz	20 people got in	
08:30	Polish BUS	Warsaw	20 people got in	

Time	Operator	Direction	The numer of people	The number of people getting off
08:42	VIKI	Warsaw	25 people got in	5
08:45		Ukrain	4 people got in	
09:33	from Staszow	Warsaw	10 people got in	1
09:33	VIKI	Warsaw	15 people got in	7
09:48		Zakopane		1
09:48		Krynica Zdroj		1
11:06		Ciechocinek	20 people got in	2
11:06		Lublin		3
11:11		Warsaw	1 people got in	2
11:15	VIKI	Warsaw		6
11:21		Warsaw	5 people got in	6
11:40	VIKI	Warsaw	10 people got in	
11:40		Cracow	5 people got in	
14:05			25 people left	
14:04		Warsaw		2
14:54		Warsaw	5 people got in	12
15:02	VIKI	Warsaw	15 people got in	9
15:06		Starachowice	2 people got in	3
15:19	Polish BUS		20 people got in	30
15:27		Tarnobrzeg	8 people got in	5
15:49		Warsaw	3 people got in	1
15:45		Jasło	5 people got in	3
16:05	VIKI	Warsaw		20
16:10		Warsaw	1 people got in	6
16:30	Polish BUS	Warsaw	21 people got in	
16:25		Chełmn	5 people got in	7
16:34		From Warsaw		15
16:55		without a plate	5 people got in	5
16:57	VIKI		15 people got in	
17:16		Łódź	16 people got in	2
17:17		Rzeszow	5 people got in	3
17:17	Polish BUS	Warsaw	2 people got in	30
17:27	VIKI	Warsaw		4
17:37		Staszow		5
17:50		Warsaw		8
17:57		Warsaw	3 people got in	1
18:18	VIKI	Warsaw		
18:20	Polish BUS	Warsaw		40
18:38	VIKI	Warsaw		6
18:56	VIKI	Warsaw	17 people got in	
18:42		Stalowa Wola	10 people got in	12

Source: own material.

It should be pointed out that a detailed exchange of passengers of buses and passengers of private buses running from the bus station or having their intermediate stops there, performing an analysis of pedestrian traffic at the PKS station is a phenomenon worth of further analysis. The results of passenger exchange observations at the PKS station in Radom were presented in a tabular form (Table 10) with reference to the operator, the direction of travel, the number of persons, including the number of persons disembarking in the context of time intervals.

Passenger traffic at the PKS station (Table 10) is mainly related to the activities of two carriers: VIKI and Polish BUS, which offer connections on the route Radom–Warsaw, Warsaw–Radom, both in the morning, at noon and in the afternoon. As part of the exchange of passengers in the morning hours, these are usually people getting in, and in the afternoon, people getting off, but this direction is not the same in all time intervals. Between 6.02–6.45 and 8.05–8.48, as well as at 4.30 pm, the largest number of people got in the chosen means of public transport and left in the direction of Warsaw, while the most, as many as 40, got in at the bus station at 18.20.

The number of passengers entering (so one should assume that those leaving Radom, Table 11) are larger than those leaving in the case of PKS station and the BUS stop (in this case significantly larger). However, in the case of the PKP railway station, the situation is reversed. The coefficient of variation in the case of the number of outgoing people is clearly larger than in the case of the number of people entering – it is the only one for the PKP railway station exceeding 100% and amounts to 124.5%. On the other hand, the PKS station is relatively low for the number of people entering. In all the cases, the median is clearly smaller than the average value. It should be noted that in the case of the PKP railway station, the maximum value is greater than the median value by more than four times the standard deviation (quadrant deviation – in the case of passengers almost five times). A similar situation occurs in the case of the PKS station for the number of outgoing passengers, whereas for the quarterly deviation from the median it is almost 6.5 times. In statistics, this value is referred to as outliers. For other cases, this ratio ranges from 1.7 to 3.5.

Table 11. Basic statistical parameters defining the specificity of the intensity of people's movements carried out on foot in the areas covered by field research

	Average	Standard deviation	Volatility indicator [%]	Min	Q1	Me	Q3	Max	Quad deviation	Total number of people
PKP entering	37.6	30.5	81.2	2	15.75	31.5	47	165	31.25	1654
PKP outgoing	44.7	55.7	124.5	0	6	29.5	61.25	294	55.25	1967
PKS entering	27.3	11.8	43.3	8.0	18.8	24.5	35.0	60	16.3	1201
PKS outgoing	24.9	22.0	88.4	0.0	13.0	20.0	30.0	130	17.0	1095
BUS entering	13.0	8.2	62.6	3.0	6.0	11.0	20.0	35	14.0	573
BUS outgoing	10.1	9.6	95.2	0.0	3.0	6.0	15.0	44	12.0	446

Source: own material.

Summary

Shaping transportation behaviours of city dwellers is a very important process for the proper functioning and development of a city. Every passenger making decisions regarding the way of travelling in their everyday life takes into account the environmental aspect – qualitative. It is very important to strengthen the role of collective transport, which is an important factor in improving ecological conditions, as well as reducing the costs of congestion. It is essential that the collective transport system operate effectively and be open to the diverse needs of its customers.

Change in transportation behaviour, consisting in shaping demand by changing the approach to collective transport – rail and bus, as well as to the ways of travelling, is primarily designed to achieve rational and sustainable movement.

Transportation behaviours can be shaped in the context of pedestrian traffic in transport nodes using various instruments. The most common include economic, administrative, legal and information instruments, including the purchase of transport means, expansion or modernization of infrastructure – bus stations and bus stops, as well as financial tools such as parking fees, which are usually top-down solutions by the city authorities.

The effective application of these instruments can increase public awareness – influence the attitude of the society – and, as a result, change their transportation behaviour and preference. In addition, an extremely important element of the public transport system is to provide the necessary information on alternative ways of people moving. Such activities are aimed at disseminating relevant knowledge about environmentally friendly transport means, as well as analysing the existing conditions, seeking solutions, and also assessing possible travel alternatives, for example in terms of time and travel costs.

Analysing the transport system in order to select transport nodes, it was found that in Radom there is basically one area that performs such a role around the bus and railway stations. The square in front of the railway station and Belina Prażmowskiego St. in front of the bus station also serve as a station for private suburban (BUS) and interurban transport (minibuses and buses not using the bus station) and the most important transport hub (also interchange) for public transport. It should be noted that there is a P-R car park between the bus station and the PKP (it is mainly used by people reaching Warsaw by rail), which generates additional pedestrian traffic (and not only). The intensity of pedestrian traffic at particular times of day and means of transport for this interchange was measured. It would be appropriate to repeat the research due to the construction of the downtown expressway (the so-called NS), one of the sections of which runs through this interchange, the western ring road (S7 route), modernization of the Warsaw–Radom railway line and structural transformation of Radom. Surveys on mobility of Radom residents indicate a very small share of public transport (18%) in the ways of travelling. Passenger car journeys constitute over 53% and pedestrian journeys over 24%. In the case of pedestrian journeys, less than one third are combined journeys. These data show that there is a great potential for increasing the share of public transport in the case of Radom. It will be important to design the bus line network in a proper way, taking into account interchanges, including multimodal ones. In practice, Radom does not have any interchanges. Due to the above-mentioned changes in the infrastructure and expansion of the bicycle paths network, starting the city bicycle system and a significant decrease in unemployment it would be appropriate to repeat the research.

On the basis of the analysis of pedestrian traffic intensity at transport nodes in Radom it can be stated that depending on the traffic generator, type of public transport, as well as the time of day it is different. Certainly, an important factor of such a development of traffic intensity are qualitative features typical for both rail and road transport. In a way, they determine first of all the choice of the mode of transport, and then within it – the means of transport in order to satisfy the transport needs in accordance with the preferences and transport behaviour of the surveyed passengers.

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