COMPARISON OF TRANSPORT SYSTEMS IN RURAL AND SUBURBANIZED AREAS WITH REGARDS TO ENERGY CONSUMPTION AND TRAVEL SPEED

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Abstract. The aim of the research is to describe transport systems of public transit focused on the service in rural or suburban locations. The former rural settlements have become suburbanized areas of the cities' hinterlands where the transport demands are satisfied by private car usage increasingly. The surveyed settlements are a part of the "suburban sprawl" process in the suburbanized hinterland of Prague catchment area. The regionally-dominant position of Prague city strongly affects the transport links between rural centres. The traffic congestions and prolongation of the travel time significantly decrease the travel speed and increase energy consumption of commuting. These facts have a negative impact on competiveness of public transit to compare with private car transport. 10 suburban settlements were selected for the purposes of fuel consumption investigation and for travel speed assessment. The authors have focused on the journeys carried out during the morning peak hours of ordinary working days when the transport demands are saturated. The obtained results have proved significant benefit of fuel savings associated with the public transit usage to compare with private car usage. But on the other hand, there is a low competitiveness of public transit in the field of travel time.

Keywords: suburbanization, public transit, passenger car transport, travel time, fuel consumption.

Introduction

The process of suburbanization and desurbanization (or also called deurbanisation) is described as the most difficult stage of the residential development with regards to the public transport service [1]. The transport demands are realized for a long travel distance and the passengers demand high accuracy of transit connections and sufficient transport capacity during peak hours. Public transport provides the population mobility in relation to the core city (radially oriented journeys) and also within micro-regions, where the intensity of transport demands is usually significantly higher in relation to the city to compare with micro–region relations. The scope of the public transport system is expanding further into the regional area due to growth of the city catchment area. Commuter trains are needed to cover the most important transport links as a backbone of the transport system [2; 3]. Therefore, it is appropriate to integrate the commuter trains into an integrated transport system with including common tariff rules.

The passenger's decision which transport mode would be used depends on the travel costs, travel time of journey, traveling comfort and other personal preferences [4]. The final decision is the mix of previous conditions which are either accepted or not. The role (or challenge) of transit is to offer transport within the range of acceptability for majority of passengers and to become the best alternative. Typically it is a compromise between the travel time (or travel speed consequently) and travel costs [5]. The dependency on a usage of passenger cars is growing and at the current pace of growth is not sustainable [6].

The changes of transport behaviour occur in connection with the previously mentioned factors. The newly built suburban settlements have a high passenger car dependency at modal split [7] to compare with the municipalities without suburbanization development. Transport demands of suburban settlement residents are carried out in relation to the core city. This situation contributes to the occurrence of traffic congestion and it increases the fuel consumption during the commuting from suburban settlements. Therefore, it is possible to observe increased energy consumption concerned with the suburban transport in comparison with the regional transport in rural areas [8].

Increased population mobility and transport accessibility have allowed factual development of suburbanization. The increased availability of private car transport and the passenger's demands to increased travel speed have caused the growth of traffic volume and an increase of travel distance [9]. This kind of development has led to the preference of private car transport. On the other hand, this fact is also valid in the opposite meaning. Suburbanization and diffused forms of settlement have caused the need of increased mobility demands of inhabitants, and it creates a dependency on accessible and cheap energy [10]. This fact creates interdependence of these factors. The legislative effort of the European Union was focused on the energy efficiency of buildings, until nowadays. The issued directive requires the construction of houses with energy consumption close to zero since 2020 [11]. Energy efficiency of buildings has been taken into the strategic targets of energy savings at the European level. This effort is devalued in the context of fuel consumption in relation to commuting from the suburban settlement to the core city. The expended resources are devalued through energy demands associated with the location of suburbanized areas.

Materials and methods

In the research 10 localities of suburban settlements were chosen with the aim to describe suburban residents' energy consumption during their commuting. The surveyed settlements are situated in newly built suburban localities with specific built up area also known as urban sprawl (or suburban sprawl) and these settlements are the only part of the original municipality. Some settlements are listed only administratively as a part of municipality and they are built as a separate settlement far away from the original center. The most of these settlements were built after 2001 and the construction of new houses has gone on there up to nowadays. These surveyed settlements are influenced by the catchment area of Prague city that is the dominant city of the region. The chosen settlements are localized by to 25 km from the Prague city center and up to 19 km from the nearest public transport terminal. These suburbs were chosen evenly in different directions from the Prague center with no satisfactory commuter train connection, thus public transit is implemented as suburban bus transport only. The suburban settlements represent different type of buildings, level of public facilities etc.

The experimental fuel consumption investigation of the journey (the fuel consumption survey) was carried out during the morning peak hours (from 6 to 9 am) during ordinary working days. The survey time covered uniformly the morning peak hours in all of the surveyed settlements. The journeys were coded ("J 1" – "J 10") in accordance with the name of the municipality (Říčany;Psáry; Sulice; Hostivice;Bašť; Jenštejn; VelkéPřílepy 1; VelkéPřílepy 2; Holubice; Chýně) where they come from (see Fig. 1).The travel time and fuel consumption of combustion engine were measured under real conditions of traffic flow by measuring buses and measuring cars (floating car data method). Public transit surveys also included investigation of the travel speed and investigation of time delay during the journey (departure time difference from the time schedule). It was sufficient to evaluate journeys from settlements to the nearest available underground station (public transport terminal) for the purposes of the research, where the "Park and Ride" parking lots are located as well.

The fuel consumption survey included an investigation of commuter bus fuel consumption and of passenger car fuel consumption. On base of these fuel consumption surveys, the authors found out the total fuel consumption of the bus and of the passenger car to the journey. The journey to the best reachable public transit terminal with the 'Park and Ride' parking lot was considered. Altogether 34 journeys (395 km in total) were carried out from all of 10 surveyed suburban settlements during the morning peak period. The measuring journeys were repeated more times if the fuel consumption or travel time varied in a wider interval (especially congested journeys "J 1", "J 2" and "J 3). On the other hand, the short measuring journey with the fluent traffic flow was sufficient to repeat only two times (journey "J 10"), since there is no variation of the fuel consumption and of the travel time during these journeys.

The journeys were carried out through the concurrent ride of the measuring bus and of the bus under the ordinary operation with passengers, where the bus occupied by passengers was followed by the measuring bus. Thus, the ride, current speed, acceleration, deceleration and the bus stops of the measuring bus were maintained under real conditions. The impact of the driver was limited by leading the bus that was occupied by ordinary passengers, thus there was no room to drive under inappropriate speed or increased acceleration. The measuring bus was not possible to occupy by ordinary passengers, therefore it was necessary to simulate the vehicle occupancy by ballast weight. The total weight (the ballast weight and the weight of measuring equipment) corresponded to the occupancy by 31 passengers (all seats occupied).

Karosa B951.1713 was used as a measuring bus; the engine: Iveco Cursor 8 F2B; the power of the engine: 180 kW; the engine displacement: 7.8 liters; complying with the Euro 3 emission standard; the fuel: diesel; fully automatic transmission Voith D 851.3. This type of bus is commonly deployed on the suburban bus lines nowadays. Škoda Fabia 1.2 HTP was used as a measuring car (economy car); the engine: HTP (High Torque Performance); the power of the engine: 40 kW; the engine displacement: 1.198 liters; complying with the EU 4 emission standard; the fuel: gasoline; manual transmission.

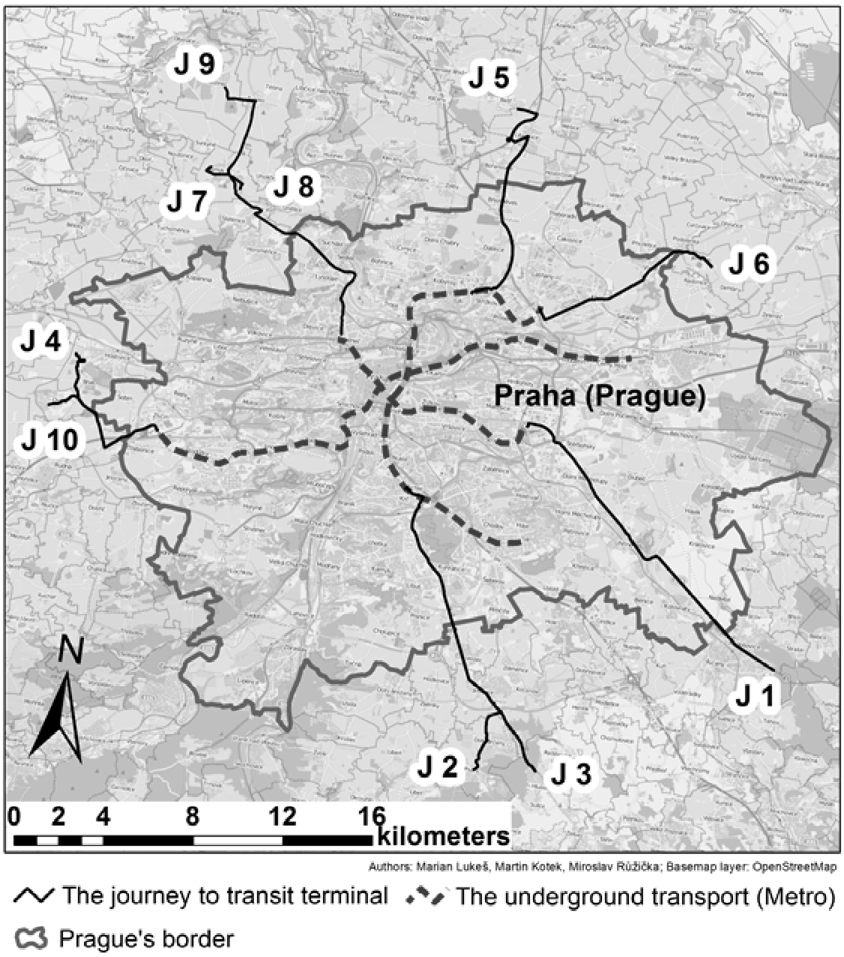

Fig. 1. **Location of surveyed journeys from initial suburban settlements**

The measuring bus was equipped with a differential flowmeter DWF as a fuel gauge. This fuel gauge was connected to the suction pipe and the return pipe of the bus fuel system. The output signal is a pulse with the transmission through the Hall sensor. The fuel gauge was connected to the datalogger, which recorded each pulse of fuel gauge. These data were transmitted further to the processing device (notebook), where pulses were counted and comparison between the instantaneous values obtained at the suction pipe and at the return pipe of the bus fuel system was carried out. This difference represents the instantaneous fuel consumption. The external GPS receiver was also connected to the processing device and the GPS receiver provided the data on the position, speed, azimuth, number of available satellites and the magnetic declination. The battery power was used as a source of electrical supply for the fuel gauge through the display. The data of the passenger car fuel consumptions were gained through the OBD connector (On-Board Diagnostics) and it was supplemented by GPS data. The energy density of fuels was considered as 32.18 MJ per liter of gasoline and as 35.86 MJ per liter of diesel [12] for the purpose of energy consumption calculation.

Results and discussion

One of negative consequences caused by the increasing suburban car dependency is an occurrence of traffic congestions. These congestions influence passenger car transport and suburban bus transport in the same way (see Fig. 2). The travel speed of the passenger car is higher in all cases than the travel speed of public transit and this illustrates a fact that no tools of public transit preferences are used there.

The public transit operator offers the time schedule for its bus lines that are presented as departure times at the every bus stop. The term “Delay of public transit from schedule” describes the delay time at the final stop of the bus line. Thus, it is the time gap between arrival of the bus to the terminus according to the time schedule and real arrival time of the bus to the terminus. Average value of the delay time is divided to each settlement. Figure 2 shows association between these local delays and real travel speed. It is possible to say that the increase of the delay time is caused by the decreasing trend of the travel speed. This fact was confirmed by the determination coefficient ($R^2 = 0.825$) and positive correlation of these two factors was validated by the Pearson's correlation coefficient ($r = 0.895$). These delay times from the time schedule are caused by occurrence of traffic congestions and maximum average value per settlement is 28 minutes of delay time (see journey "J 1"). This fact makes bus public transport unreliable, uncomfortable and with a very low competitiveness in that case.

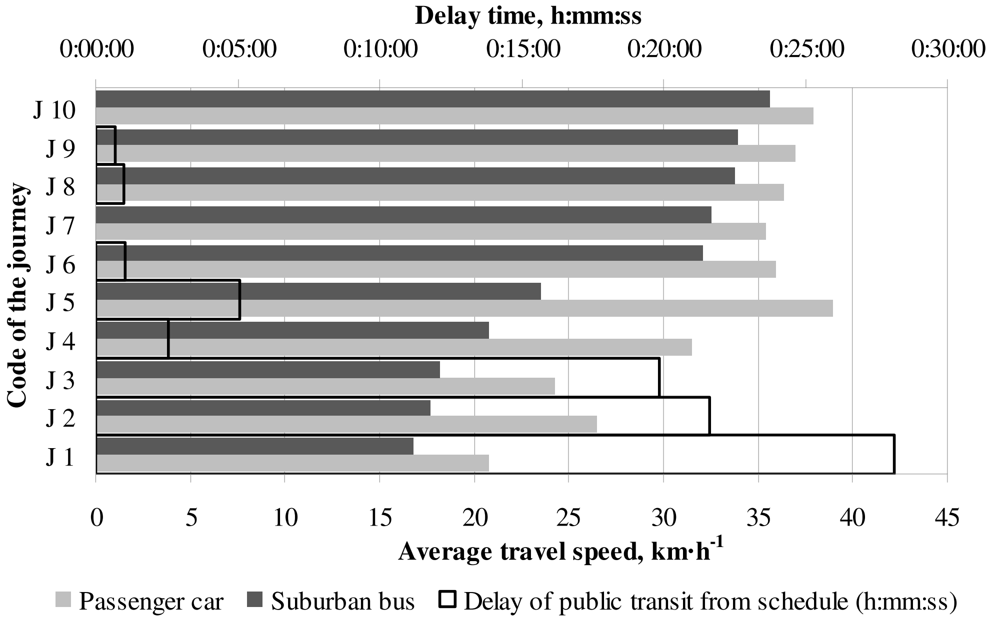

Fig. 2.**Travel speed of public transit and passenger car transport**

The evidence of this low competitiveness has shown an evaluation of modal split in the surveyed settlements that was carried out during the previous stage of traffic surveys [7]. The average values obtained from all of surveyed settlements have proved the dominant position of passenger car usage during the peak period. 80 % of all transport demands are satisfied by passenger car transport, app. 20 % of transport demands are satisfied by public transit and the minimum proportion of cycling transport (0.5 %) was found out in surveyed settlements. The modal share of passenger car transport varies from 90 % to 54 % of transport demands with regards to the surveyed settlements. The price level of fares is not a motivating factor for a wider public transit usage in the surveyed locations [7].

The most of the congested journeys have the highest proportion of low speeds during 7-8 am. It is mainly caused by the saturation of the transport demands linked to home–to–school journeys (pupils and students) during this period. These transport demands are complemented by the transport demands of the ordinary commuters (home–to–work journeys). Therefore, the total transport demands are saturated during this period. It is evident that the most congested transport relations come from the southeast of Prague at the journeys "J 1", "J 2" and "J 3" (see Fig. 1 and Fig. 2). This area is strongly influenced through the uncoordinated development of suburbanization [13].

Overall, the fuel consumption investigation of suburban bus lines was carried out to 422 km of measured bus line journeys and the fuel consumption investigation of passenger car was carried out to 304 km of journeys. All of the journeys were carried out during the morning peak hours. The peak journeys by the suburban bus were compared with passenger car transport (see Fig. 3). There was used an uniform unit ($kWh \cdot km^{-1}$) for the purpose of appropriate comparison of two different fuels – the suburban bus with a diesel combustion engine and the passenger car with a gasoline combustion engine.

The journeys that are congested during the peak hours have shown higher energy consumption than others and it has been proved that the suburban bus usage has less sensitive on energy consumption than the passenger car under congested journeys. On the other hand, the high tortuosity of track and hilly vertical alignment of journey are more evident at the increased fuel consumption of public transit than it is at the fuel consumption of passenger car transport. The public transit usage has been proved as an important element of reducing energy consumption of transportation. The exact evaluation of energy consumption (see Fig. 3) provides the comparison to the results declared by other authors [14; 15].

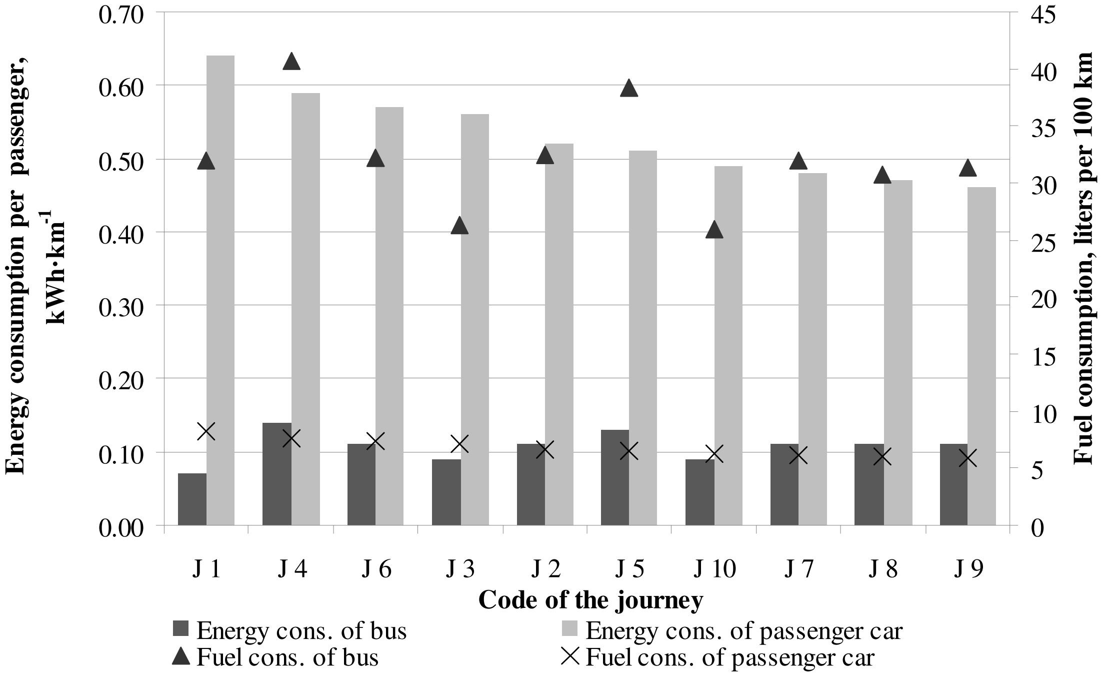

Fig. 3. **Energy and fuel consumption of public transit and passenger car transport**

The obtained results suggest the accordance to [14] in case of energy consumption of the passenger car (0.48 kWh·km^{-1} per passenger). But there are considerable differences to energy consumption of the suburban bus. The authors [14; 15] have presented the higher level of bus energy consumption. The authors [15] have distinguished the values for the city bus (0.25 kWh·km^{-1} per passenger) and coach (0.32 kWh·km^{-1} per passenger), but there are not the values for a suburban bus available. The obtained results have proven lower energy consumption of bus under suburban conditions (0.07-0.14 kWh·km^{-1} per passenger) than it has been presented by other authors [14; 15].This difference could be caused partially by different level of considered bus occupancy, but it could not be expected that the city bus would have lower occupancy rate than the suburban bus (all seats occupied).

The energy consumption equilibrium between the passenger car and transit occurred when the occupancy of bus is quite low – between 4 and 7 passengers (depends on the journey from the surveyed settlements).Public transit and the passenger car have had the same energy consumption at this interval of occupancy as the suburban bus. Any higher occupancy of the bus has had energy consumption benefit on the side of public transit to compare with passenger car transport. It should be pointed out that this statement is valid for the used type of bus. It is possible to assume that newer buses or midibuses have better economical operation. Therefore, the energy consumption equilibrium between a passenger car and transit could be expected at the lower end of occupancy interval from 4 to 7 passengers.

Conclusions

As it has already been shown, the travel speed of public transit is every time lower than the passenger car speed and public transit is hardly competitive to the passenger car in the field of travel time and time efficiency generally. It would be worth to implement effective tools of public transit preference in congested parts of journey, since transit and cars share the common road for transport nowadays and there is no perspective that the railroad will be built into the surveyed settlements. This would have a beneficial effect on the fluency of public transit vehicles and it could determinate the principles for the implementation of the BRT system (Bus Rapid Transit system). On the contrary, the effort to increasing passenger car travel speed tends to increase passenger car usage (induced transport demands) and this causes problems of congested roads again without satisfactory solution.

The public transit usage has been proved as an important element of reducing the energy consumption of transportation. Effective public transit could offer interplay between the tasks of spatial planning and satisfaction of the transport demands. The energy benefits of public transit usage are significantly increased with the growing trend of vehicle occupancy. The energy efficiency of bus public transit allows to accomplish similar energy consumption per passenger as an ordinary passenger car has at a low occupancy rate of bus (from 4 to 7 passengers).

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