GeoScience Engineering

URBAN PUBLIC TRANSPORT SERVICES IN SELECTED CZECH TOWNS

Jiří HORÁK, Pavel KUKULIAČ, Ondřej KOLODZIEJ

VSB – Technical University of Ostrava, Faculty of Mining and Geology, Department of Geoinformatics, Ostrava, Czech Republic
E-mail: jiri.horak@vsb.cz

ABSTRACT

Urban public transportation systems in 26 selected Czech municipalities are studied using their timetables, location of stops, and price survey. The methodology of their processing is proposed. A set of indicators describing spatial accessibility, performance, and prices are analysed mainly for their relationships to the population with an indication of the municipalities which most deviate from common trends. A proposed four-dimensional evaluation system covers the spatial accessibility operationalised by the number of stops, the service frequency using the number of trips per route, the velocity for selected transport mode and the cost assessed by the price of a one-year ticket or equivalent. The results show the fare fees do not correspond to the performance of urban public transport.

Keywords: Cluster analyses; Czechia; Public transport; Regression analyses; Time schedule; Urban transport.

1 INTRODUCTION

Urban Public Transport (UPT) represents the most important mode of public transport according to the number of passengers. In 2015 UPT transported 2160.8 mil passengers in Czechia, which accounted for 80% of the total public transport (PT) and 44% of the total passenger transport [1]. The dominant role of UPT within PT persists, and the differences in the last five years are not significant. The share of passenger transport performance (pskms) in UPT represents almost 37% of all PT and 14% of the total passenger performance; the smaller percentage is due to shorter trips.

Despite the doubtless importance of urban public transport systems (UPTS), the UPT still stays away from the main interest of geographers. While national or regional public transport evaluations are relatively frequent topics, especially when discussing poor transport serviceability of rural and peripheral areas [2–4], the evaluation and comparison of UPTS are missing.

Timetable data are commonly used for PT passenger routing. Secondarily, they can also be utilised for analysing the structure and organization of PT networks [5–7], comparing how PT networks are structurally organized across cities [8–11] as well as the accessibility and the level of service these networks provide [7, 12–14].

Utilization of public transport tables for geographical research purposes is not rare, but they are usually used to calculate frequencies of transit connections or vehicles in selected time periods between Origins and Destinations to measure the intensity of interaction. Michniak [15] utilizes the frequency of links to analyse international linkages of districts in Slovakia as a proxy for the intensity of interactions. Marada et al. [16] evaluate public transport time schedules for the years 2000 and 2006 using the weighted frequency of connections.

The usage of urban public timetables is quite rare. The spatial accessibility of urban PT stops in České Budějovice was studied by Kraft [17]. The accessibility of supermarkets and hypermarkets in Bratislava was evaluated by

Križan [18], who uses travel time between each urban district and supermarkets calculated from timetables to evaluate accessibility in the urban environment using eight different types of accessibility measures. Horňák et al. [19] have studied direct train and bus links from the timetables of 1989, 1999 and 2011 to analyse the accessibility and changes of accessibility of eight Slovak urban centres. Nykl et al. [20] evaluated urban transport accessibility using timetables for public transport analysis, an innovative Dijsktra's algorithm, and complete maps of road, footpath and cycleway networks.

The aim of this study is to demonstrate the ability to elaborate a set of indicators for an effective quantitative evaluation of UPTS from timetables, to evaluate and compare selected municipalities of various sizes across Czechia and to reveal to what extent the level of UPT services determined by the municipal size. It arouses the following research questions: How to evaluate the level of UPT services? Is the population the main influencing factor? Does the price for customers correspond to the level of UPT services?

2 EVALUATION OF UPTS

The evaluation of UPTS varies from the most complex and multidimensional characteristics to short lists of selected factors suitable for specific purposes. Basically, we can distinguish objective and subjective indicators where the latter group refers to a direct evaluation of attitudes, feelings and opinions of passengers, which are usually analysed from surveys, social networks or monitoring of travel behaviour. Obviously, subjective factors reflect some level of the objective criteria that may be understood as primary factors.

The complexity of evaluation is related to our effort to create a sustainable urban transport system (SUTS). It requires strengthening various system features, including accessibility and mobility, reliability and efficiency, as well as safety and security, social equity, convenience and comfort [21]. Addressing all features and creating a universal evaluation is a very hard task. For example, Ľupták et al. [22] specified the quality of the provided transport services by a set of the following aspects: regularity, reliability, safety, speed, economy, reasonable cost, ecology, comfort, performance and availability; nevertheless, the proposed factors were measured by descriptive (quantitative) indicators like several types of time, distances, speeds and the number of connections, whereas the only qualitative aspect was the type of train. Al Mamun and Lownes [23] provided a more concrete set of recommended measures: Service Coverage, Time-of-Day, Waiting Time, Service Frequency, Demographic data, Vehicle Capacity, Route Coverage, Travel Time, Travel Cost, Hours of Service, Walking Route, Access distance, Comfort & parking, and Network connectivity.

Other authors are focused only on selected criteria which, according to their opinions, dominantly influence the efficiency and utilisation from the user's point of view. For example, according to Ceder et al. [24], an effective public transport service can be defined as minimum in-vehicle travel time and waiting time; Avila-Torres et al. [25] emphasize also low fare in addition to less travel time and less waiting time. Some authors advocate the key role of direct connections in public transport utilisation, e.g., Krizan et al. [26] in the complex evaluation of the accessibility of supermarkets in Bratislava or Horňák et al. [19] for the evaluation of interregional communication.

Another approach is to apply measures based on the graph theory. Brinke [27] recommended the use of network deviality, network density (related to both the area and the population), and connectivity.

We can summarize that the following key objective factors are considered:

1. Spatial accessibility of the transport – appropriate metrics are the network density, number of stops, stop density, operational length or average distance of stops. For the integration of uneven spatial distribution of sources and destinations, it is recommended to calculate also shares of population, buildings, or POIs well accessible from stops.
2. Service frequency – related to waiting time, with appropriate indicators of the number of departures per stop or the number of trips per route. Alternatively, the number of trips per day can be applied as a joined indicator for both accessibility and frequency.
3. Velocity – related to in-vehicle time, expressed directly by the average speed.
4. Fare – expressed by the annual subscription (price per year).

We can conclude the ideal UPTS has high accessibility (high net density, low distances), high service frequency (low waiting time, high trips per route, high trips, high departures), high speed, low fare, high variability and low deviality. Corresponding structural and performance indicators should be a base for a comprehensive quantitative evaluation of UPT.

A critical aspect is time. A variation of indicators during a day or week cycle should be included in the evaluation. In this study, temporal changes are reflected by indicators enumerating differences between services on Wednesday (Wed.) and Sunday (Sun.).

3 DATA SOURCES AND METHODOLOGY

Information about the geographical extent of UPTS in Czechia is not easily available. We can evaluate the status according to the list of downloadable urban timetables on the CHAPS (the administrator of the National Information System on Regular Public Passenger Transport Timetables) website. Of 6253 municipalities (middle 2015), 103 declare to have their own urban transport. Of course, many other municipalities, especially on the outskirts of large cities, are served by a public transport company operating from the central city. For example, Prague Public Transport Company Inc. operates in 39 other municipalities, Brno Public Transport in 23, and Ostrava Transport in 20 (November 25, 2015). The expansion to the surroundings continuously grows, especially in the case of Prague, where, since 2015, new external zones 8 and 9 were added. The evaluation is complicated by joining UPTS into regional PT systems, which may cover the full NUTS2 or an even larger area (Fig. 1). The integration of PT services in the case of Brno UPTS covers the full South-Moravian region.

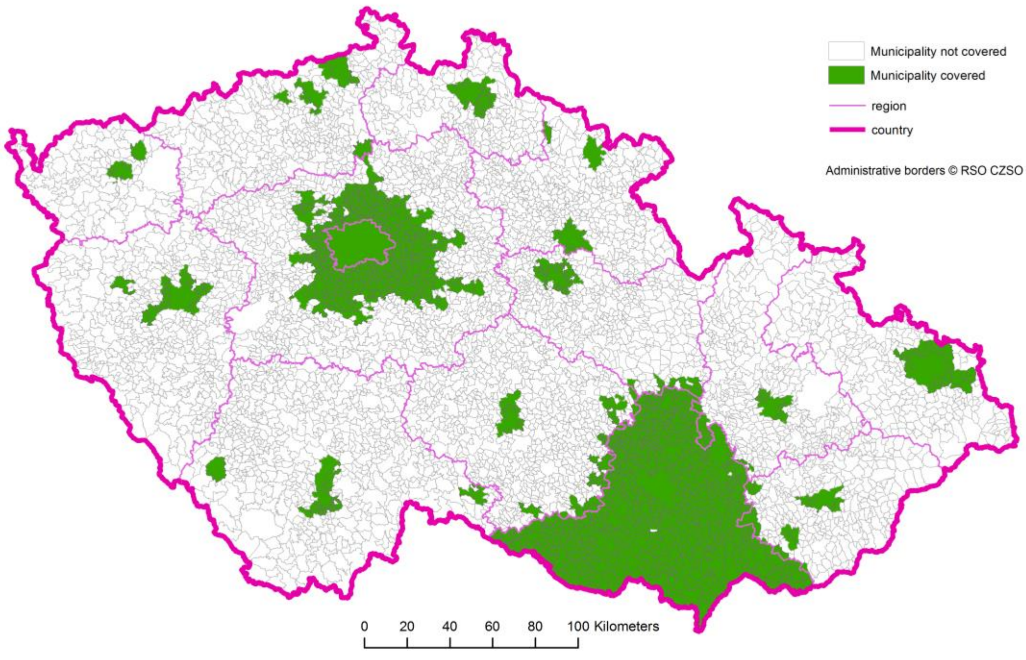

Figure 1. *Extension of integrated UPTS operated for 26 selected municipalities in Czechia.*
Source: authors' elaboration

The number, extent and mixture of UPTS complicate comparative analysis. Appropriate data is not publicly available and not free of charge. Although still more and more worldwide cities provide their timetables in GTFS format and new standardised data sets are available [28], the local PT situation in smaller towns is hidden and difficult to quantify, measure and evaluate. However, in such places, various issues can be anticipated. The high number of passengers, rich subsidies and long-term continual progress in large cities guide towards well-developed UPTS. On the contrary, smaller municipalities meet difficulties in how to assure a good level of public transport services at a reasonable cost.

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The limited financial sources and interest to go into detail in some aspects required to limit the number of analysed municipalities to 26, which represents approximately one quarter of all municipalities organising their own UPTS in Czechia. The selection covers all regional capitals and 13 smaller towns. Among various possible selection criteria, local relief is considered one of the important factors where large vertical change should complicate the service, the net construction and the speed. Hence, the digital model of relief from ArcCR500 overlaid municipal polygons, the minimal and maximal elevations within polygons were recorded and the following towns were selected: municipalities with a high elevation and high variability (Vrchlabí, Děčín, Ostrov, Vimperk, Trutnov and Jablonec nad Nisou), low variability and/or low elevation (Havířov, Dačice, Teplice, Kladno, Stříbro, Uherské Hradiště and Bystřice nad Pernštejnem).

Data on urban transport timetables from 26 selected Czech towns was bought in 2016. Full-time schedules, incl. the location of every post for urban transport stops, were exported for 2 days, November 25 (Wednesday) and November 29 (Sunday), 2015. Data does not contain timetables for any transport, but only those assigned to urban transport systems.

The important question was how to establish an appropriate range for analysis. A UPTS can contain services of different providers (including Czech Railways, e.g.) and usually covers not only the central town but also surrounding municipalities, reflecting the required sufficient transport connectivity with the microregion core. It is obvious that only large municipalities establish their own public transport company to provide UPTS. Such services in smaller towns are usually guaranteed by companies providing services in the region (i.e. KAD for Vrchlabí, Osnado for Trutnov), in the group of cities (usually pairs like Liberec-Jablonec n.N., Zlín-Otrokovice) or, on the contrary, by small private companies (Zlatovánek for Bystřice n.P. or Josef Štefl Tour for Dačice).

The study is focused on all PT services within the administrative boundaries of the main municipality, including all services (from different providers) offered to customers in the frame of the unified urban fare fees (Fig. 2). The basic idea is to evaluate how many services are provided to customers, in other words, how efficient the system is from the user's point of view. Only some of the relevant questions were evaluated for the service of the main provider (i.e., average velocity).

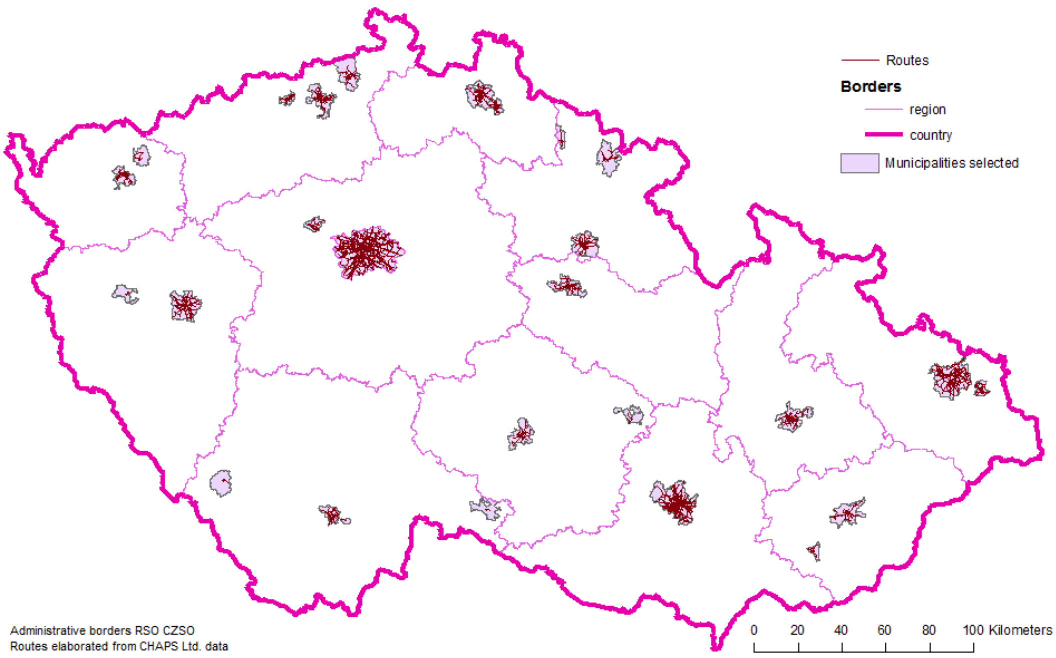

Figure 2. *UPT network in 26 selected municipalities in Czechia.*
Source: authors' elaboration

The municipal population was calculated by aggregating the population from the last census (2011) assigned to buildings (data RÚIAN, 2016) within appropriate municipal polygons. In the case of a separate municipal area,

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only the main area was selected. The population density was calculated as the ratio of this population and the relevant area.

Clearly, the delimitation of the city by administrative borders is not suitable for all purposes. A different approach was applied by Kujala et al. [28], who defined for each city a centre-point and selected the city area by spatial filtering with the specified buffer radius (from 10 to 50 km, according to the city).

Database processing played a key role in data management, control and analysis. The original data (CSV format, 126 MB) was imported into the database. The pre-processing was focused on error detection and correction of errors to assure data consistency during calculations, selection of representative trips, data aggregation, and intersection with a registry of buildings. The extent of processing may be documented by the difference between the original data and the final size of the database, which is 2161 MB.

Great attention has to be paid to error detection and repair. The data is not error-prone and contains various kinds of issues (errors, imprecisions – imprecise recording of metrage when information systems of some providers record only kilometres and not meters, inaccurate location of stops, and duplicates – repeated routes and trips due to overlapping exports for different cities or different schedule restrictions). Especially duplicates have to be carefully eliminated; otherwise, resulting statistics will be significantly biased. The seriousness of this problem can be seen from the evidence that in the original data set almost 2/3 of records are duplicated. The multilevel control system has to cross-check any form of inconsistencies in data to detect potential problems.

It was necessary to break down every route to edges representing elementary movement between two consecutive stops. For each edge, departure times, arrival times, and cumulative metrage were recorded. From this primary data, the travel time, travel and Euclidean distances were calculated.

The specific issue is how to deal with imprecise records where the cumulative distance (metrage) is recorded, with precision limited to km (no decimal places). Without corrections, the data consists of edges of zero length, which causes errors in local velocity calculations. Further control checks if the travel distance is larger than the Euclidean distance. To solve these issues, a 3-step data adjustment system was adopted. First, all stops within 1 km (all records with the same metrage = cumulative distance) were equally distributed within this kilometre. Second, the moving average was applied to smooth sudden changes between edges. And finally, the distances were adjusted to be equal to or larger than the Euclidean distance. In such a way, data consistency is assured. Another type of control calculates local velocities and checks (and repairs) all unrealistic values (speed).

The pre-processing also includes preparatory data modifications. For some tasks, a representative trip for each link (route) was selected (examples in Fig. 3). It was assumed the longest trip in working days would best represent the route. Using the representative trip, the operational length was enumerated. The second main preparatory task was to create transport stops by aggregation according to the name of the stop from the original set of all transport posts.

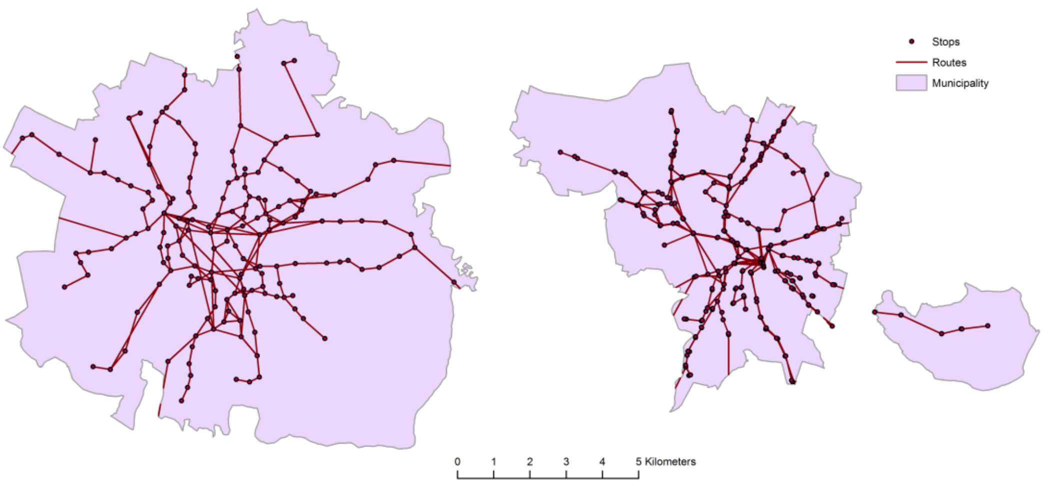

Figure 3. *Simplified transport network in Hradec Králové (left) and České Budějovice (right). Source: authors' elaboration. Stops and routes modified from CHAPS Ltd. data*

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3.1 Spatial accessibility of PT

The values of the main indicators for evaluating spatial accessibility of all explored municipalities were enumerated. We can note that the number of stops and the operational length directly depend on the municipal size, while others are considered relative or neutral indicators.

The number of stops indicates the accessibility of UPTS and its services. It is believed that a higher number (or density) of stops is more advantageous, especially in the case of local trips. Obviously, the number of stops depends on the area and population of the municipality. The regression model suggests a very high correlation (R2 for the quadratic equation is 0.994) between population and the number of stops (Fig. 4). Using 5% confidence intervals, we can distinguish an unusually high and low number of transport stops. An exceeding number of stops on working days can be seen in Liberec, Ústí nad Labem, Olomouc, Zlín, Karlovy Vary, Děčín and Jablonec nad Nisou. On the opposite, an abnormally low number of transport stops are available for residents in České Budějovice, Havířov, Kladno and Uherské Hradiště.

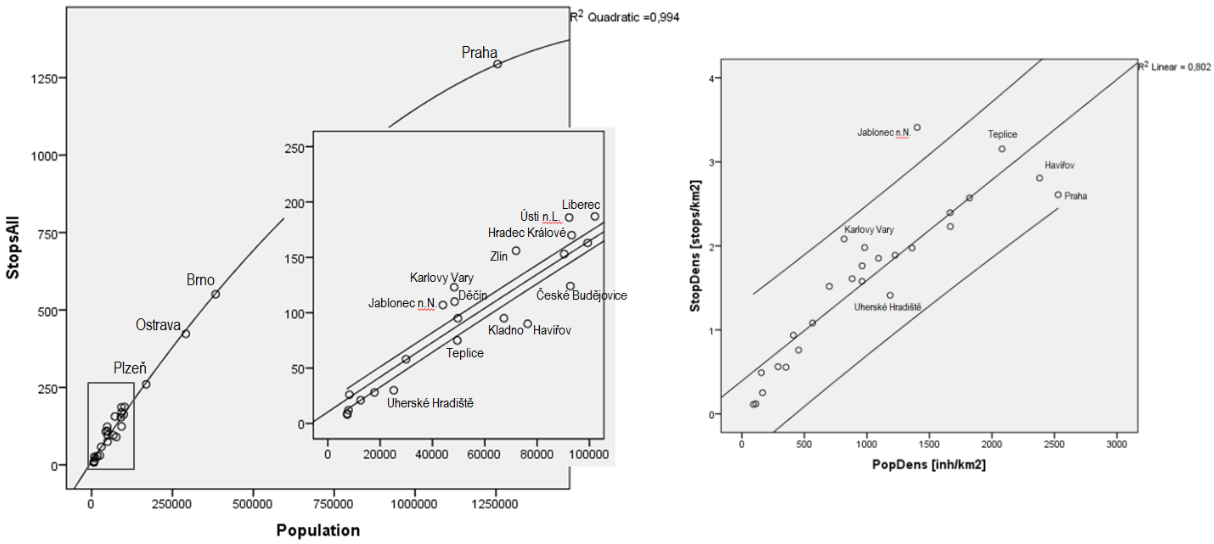

Figure 4. *Number of stops related to population (left) and population density (right).*
Source: authors

The description of the situation can be well supplemented by mapping the relationship between densities. Jablonec has the highest density of stops for medium population density. Its extreme position is clearly portrayed in the graph of the relationship between the stop density and population density (detail in fig. 4). The relatively high stop density is in Karlovy Vary, while very low density is in Prague, Havířov and Uherské Hradiště.

The temporal differences show these indicators are strongly time-dependent. Especially in small towns, we can see a dramatic reduction in the number of stops between working and non-working days. On working days, UPTS provides services for practically all stops, but on weekends the number is reduced. Differences in the number of stops are negligible for large towns (usually service declines by 2–9%), but small towns significantly reduce their service in extreme situations to zero (Vimperk, Dačice). More than a 10% reduction is met in Stříbro, Jablonec nad Nisou, Trutnov, Ostrov and Bystřice nad Pernštejnem.

The extent of the UPTS can be related to the **operational length** (Fig. 5). The operational length represents the total length of all routes inside a city for all providers without duplicate edges. It should be taken into account that the result is different from the operational length provided by the main UPTS providers. This analysis includes only part of UPT located inside the city and for all providers. Abnormally high (above 5% confidential interval) operational length inside a municipality is in Liberec, in contrast to the unusual low in České Budějovice. Quite low operational length (but not significantly low) is in Havířov, Teplice, and Kladno.

The **net density** (Fig. 5) was calculated as the sum of unique transport edges inside the city divided by the total area of the city. Similar results for operational length can be found for the regression analysis with the net density. Exceptionally high net density is in Jablonec nad Nisou; a high value is also found in Liberec, while Teplice or Kladno have very low net densities.

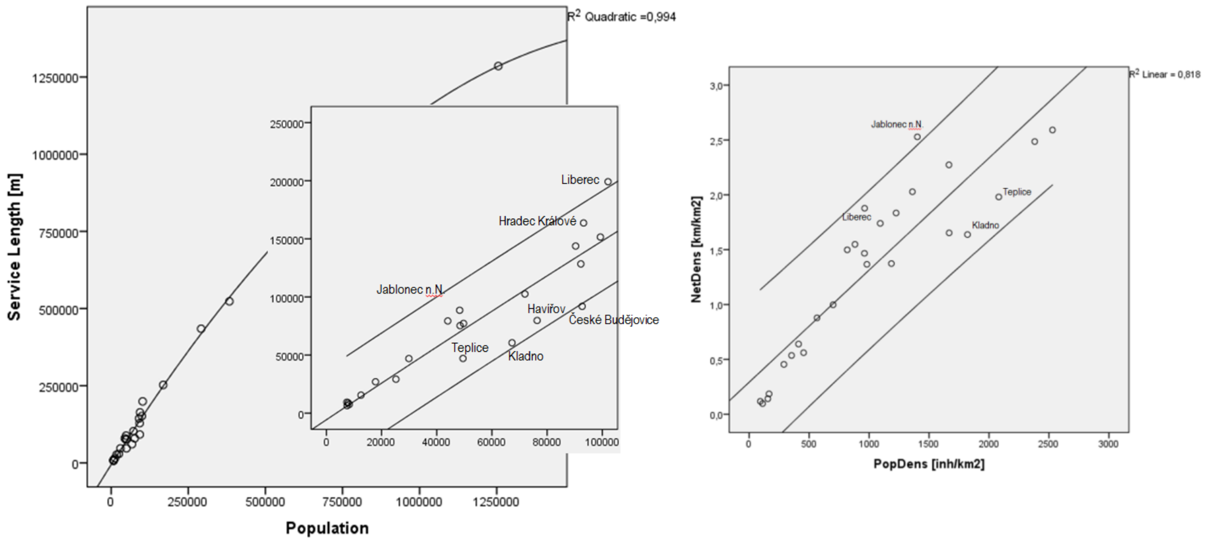

Figure 5. *Operational length related to population (left) and network density related to population density (right). Source: authors*

The average distance between stops represents a frequently used indicator related to the accessibility of PT systems. Shorter distances improve the accessibility of the service; nevertheless, it negatively influences the average speed of the transport. Short distances between stops (Fig. 6) can be found in Northern Bohemia (Ústí n.L., Teplice, Jablonec n.N.) (about 540–550 m). Distances above average are in smaller towns: Vrchlabí, Vimperk, Uherské Hradiště, and Stříbro (around 900 m).

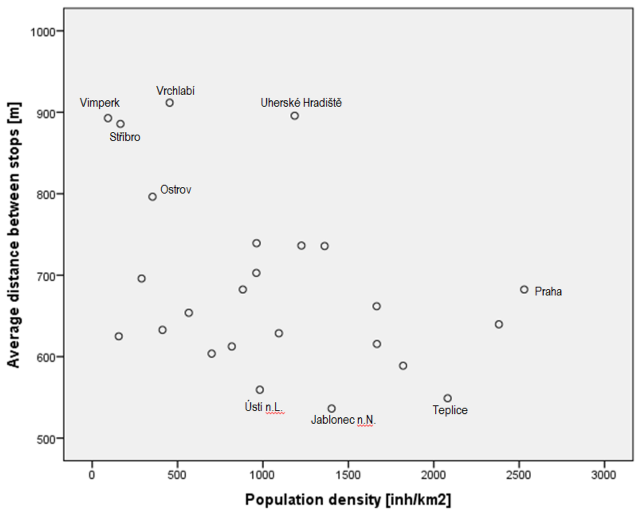

Figure 6. *Average distance between stops related to population density. Source: authors*

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3.2 Service frequency

The basic evaluation of the transport frequency can be reached from the **number of trips per day**, but it should be considered it is a joint indicator covering partly both frequency and accessibility.

A regression analysis (Fig. 7) between the population and the number of trips per day provides more simple results than in the case of the number of stops. All towns except Brno show an expected number of trips. Brno has a higher number of trips per day than expected.

More than a 50% temporal decrease can be seen in all explored towns with populations below 50,000 except for Karlovy Vary (only a 29% decrease). From larger towns, České Budějovice belongs to this group (–52%). From mid-size towns, we can also notice Olomouc has a very small decrease in service on Sunday (only a 30% decrease). Similar results can be obtained from the evaluation of all trips (not only inside the city) where the percentage decrease is the same, except for three towns, Brno (–55%), Jablonec (–61%) and Bystřice (–74%).

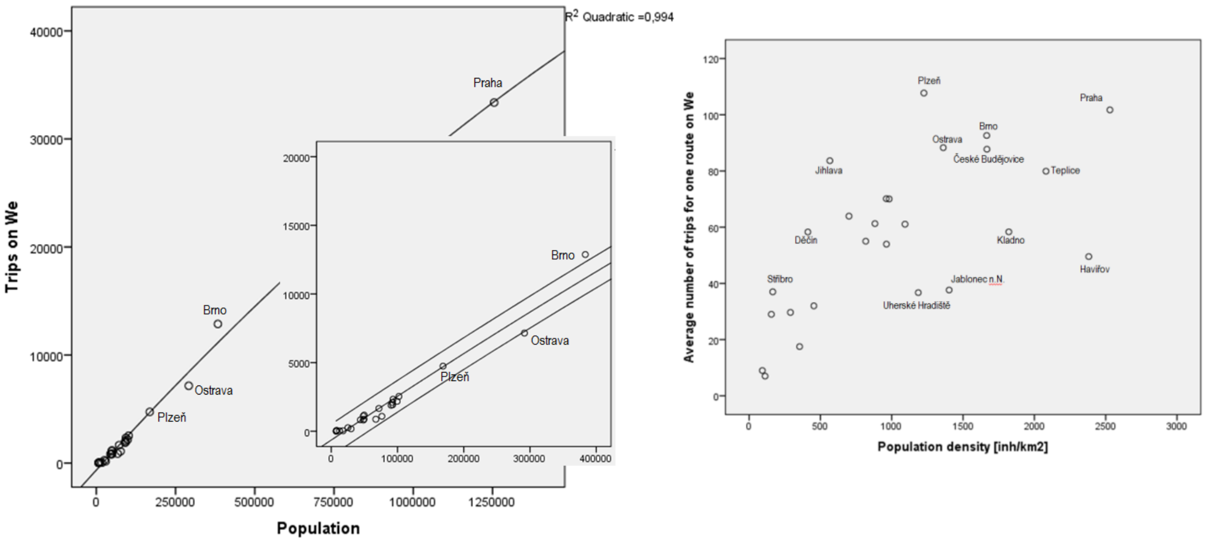

Figure 7. *Number of trips per day (left) and per route (right) related to population.*
Source: authors

The main frequency indicator, **the average number of trips for one route**, shows how routes are active. The high average number of trips per route is typical for larger cities; within them, Plzen is the leader, while Prague occupies the second place. This big tetrad is followed by some mid-size region capitals like České Budějovice (the same number as Ostrava), Jihlava, Teplice, Olomouc and Ústí nad Labem. On the opposite, Dačice and Vimperk have the weakest activity on routes.

From the relationship between population density and an average number of trips per route (Fig. 7), we can see weak activity for Havířov, Kladno, Jablonec nad Nisou and Uherské Hradiště, and a good frequency related to population density in Plzeň and Jihlava.

If we compare the average number of trips per route on Wednesday and Sunday, we found quite a wide range of manifestations from 0-change (Jablonec nad Nisou), very small (less than 20%) in Olomouc, Liberec, Hradec Králové; through usual decline around 20–30% to a serious drop down more than 50% for Bystřice nad Pernštejnem, Stříbro, Trutnov, Uherské Hradiště, Vrchlabí, and two known towns with no operations on Sunday (Dačice, Vimperk).

Another frequency indicator, **the average number of departures from each stop per day**, shows even better the positive relationships to the population size (Fig. 8). The relationship is almost linear for smaller towns (less than

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150,000 inhabitants). Further increase in the average number of departures with population is moderate and confirms the order of population size of the four largest cities.

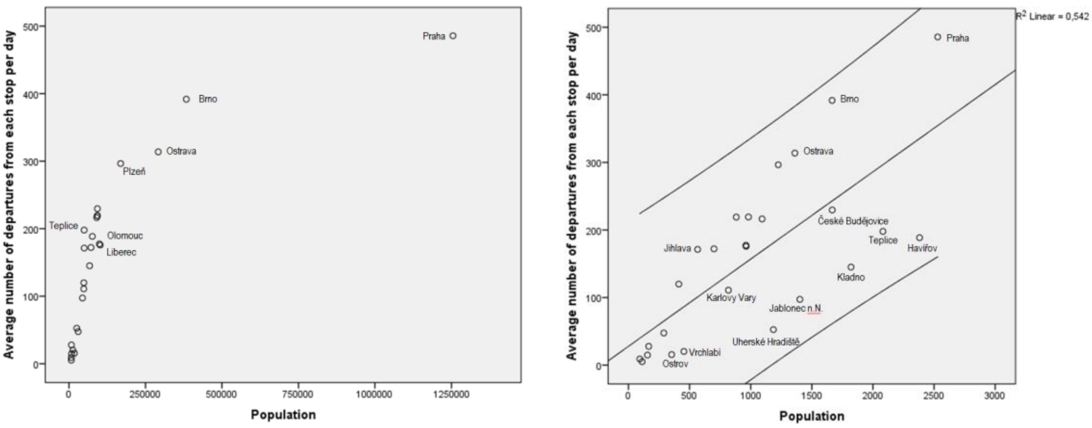

Figure 8. *Average number of departures from each stop per day related to population (left) and population density (right). Source: authors*

The relationship to population density (Fig. 8 right) is weaker (R2 only 0.542), and deviations of towns from the linear relationship are not significant, even though we can see some differences among towns. I.e., Havířov, Kladno, Jablonec, Uherské Hradiště demonstrate a lower number of departures than what is expected by the regression model.

Temporal changes (Wed.-Sun.) in the number of departures from each stop per day are not as variable as the previous indicator. The lowest changes are in Bystřice (but due to the small size of UPTS, it is not a confident result) and in Olomouc. The biggest changes (sharp decrease of the service on Sun.) are in Uherské Hradiště, Stříbro and Ostrov.

3.3 Velocity

Velocity is an important aspect of transport connection quality. It is recommended to evaluate the average velocity in a municipality according to the transport mode. The comparison is based on bus velocities, which is the only PT mode available in all municipalities.

When comparing urban bus velocity, the lowest speed is in Karlovy Vary and Jablonec n. N. (about 20 km/h), which corresponds with the idea of vertically variable and narrow streets and the occurrence of geographical barriers (rivers, etc.). Nevertheless, the relationship to the vertical changes is not simple (Fig. 9). The highest elevation differences can be seen for Děčín with below-average but not lowest velocity. The flattest relief is in Pardubice and Hradec Králové with a near-average velocity. We may conclude that local relief is less important than other transport factors. High velocities of urban buses are in Ostrov, Uherské Hradiště, Stříbro (smaller towns) and Plzeň and Ostrava from the group of large cities.

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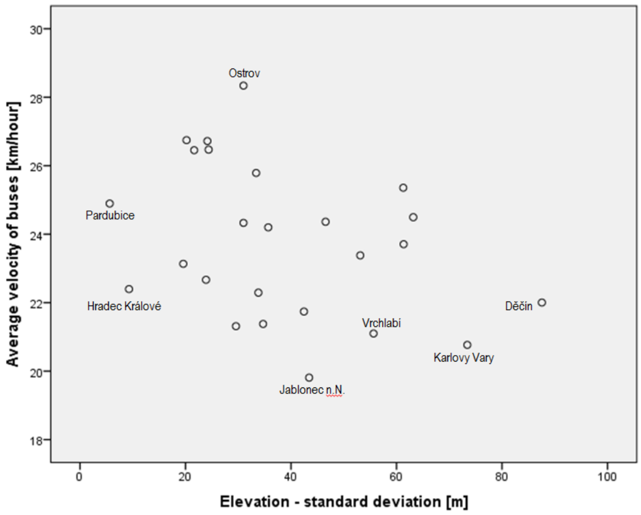

Figure 9. *Average velocity of urban buses on Wed. related to the standard deviation of elevation in the municipality. Source: authors*

3.4 Fare

One of the main factors for the suitability of public transport from the passenger's point of view is the cost of the service, namely the price for an individual passenger. The fare fee systems are quite variable, and due to applications of different reductions, combined discounts and especially mobile services, this variability still arises. Because the study is focused on UPTS conditions for residents, the price per year was selected for comparison. If the year price is missing, the corresponding multiplication of lower time fare was applied (Děčín, Kladno, Ostrov, Stříbro, Teplice, Trutnov, Ústí nad Labem, Vrchlabí, Zlín). There are no season tickets in Vimperk, which indicates the exceptional situation and limited services of this UPTS.

The simple exploration data analysis reveals there are no significant outliers, but it is possible to distinguish České Budějovice, Ústí nad Labem and Liberec as towns with a high fare, followed by Ostrava and Děčín, while Dačice, Havířov, Bystřice nad Pernštejnem, Uherské Hradiště and Trutnov, which offer the cheapest one-year tickets.

The regression analysis of price with the population or other PT infrastructure or performance indicators does not indicate any relationship. It is possible to argue that the price for the customer does not reflect real properties and offers of UPT services.

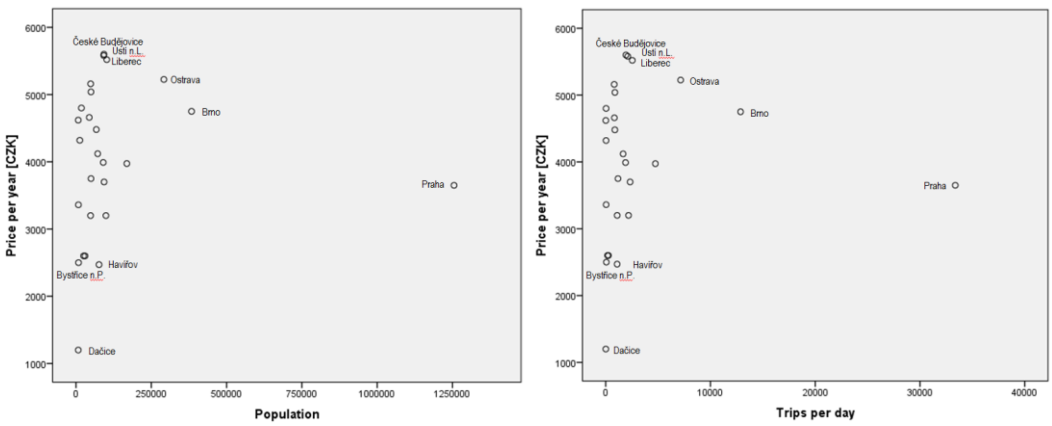

Figure 10. *Price of one-year ticket related to population (left) and to the number of trips (right). Source: authors*

4 CONCLUSION

The UPT services influence the majority of the population in their everyday life, stimulating large discussions from which many questions arise about their quality, organisation, costs, and prices. The paper introduces the extended processing of UPT timetables which enable the description of various dimensions of quantitative evaluation of UPT systems in 26 selected Czech municipalities.

The multilevel control system is focused on detecting data inconsistencies and errors. The methodology includes proposals on how to deal with imprecise distance measurements in timetables, utilization of edges, and selection of representative routes. The evaluation is focused on the situation within the administrative borders of selected municipalities and covers all providers in integrated transport systems. Four key objective factors (spatial accessibility, service frequency, velocity and fare) were expressed using appropriate indicators and evaluated for the situation at the end of 2015.

The analyses confirm the dominant role of the population in the development of UPT and the reached quantitative level of UPT services.

The proposed four-dimensional approach seems to be useful to distinguish important characteristics of urban transport systems. The following recommendations are based on an evaluation of 26 Czech urban transport systems.

Assessment of Spatial accessibility of PT can be based on the Number of stops, simple and available indicators with sufficient variability in relationships with the population. The Operation length provides similar results, but the appropriate enumeration is laborious. Also, the Net density did not bring sufficient differences in relationships with the population density, and its calculation is difficult due to the necessity to atomise routes to edges and eliminate duplicate edges. The average distance between stops is useful, providing an effective ability to distinguish UPTS conditions; however, the insufficient resolution of distances in the majority of medium and small towns leads to complicated calculations and complex solutions of consistency assurance.

The Service frequency could be assessed by the Average number of trips per route. It offers a good variance of values related to the population. Contrarily, the Average number of departures per stop is highly correlated with population and does not provide additional information.

The Velocity assessment has been confirmed as a useful indicator; however, it is always necessary to distinguish different transport modes for evaluation.

Finally, the recommendation for fare assessment (cost dimension) is to analyse prices of one-year tickets or equivalent. The interesting output is also the evidence that the fare fee has no relationship to population or selected indicators of PT performance; thus, the price is probably not (less) influenced by quantifiable factors.

This study faces various approximations and simplifications used for UPTS assessments. The main decision was to limit the study within the administrative boundaries of the main municipality covered by the given UPT system and include all providers under the condition of applying a unified urban fare fee. The population, population density and other variables were matched to this selection. The population density inside a city is heterogeneous and influenced by a share of water, forested and various other uninhabited areas. Another approach may be to use only the population density calculated for built-up areas.

The quantitative evaluation of UPTS in municipalities enables a comparison of their efficiency and performance and provides suitable benchmarks. Providers and coordinators of local or regional transport systems may see in what direction the UPT should be more developed to decrease some imbalances. Future research would focus on the classification of UPTS and its performance related to the spatial distribution of the population.

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