

LIMITS OF POPULATION DENSITY FOR EFFICIENT PUBLIC TRANSPORT IN MID-SIZE CITIES

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Abstract

This paper deals with the relationship between population density and public transport efficiency. It is focused on mid-size cities with a population of 100 000 inhabitants. The research question is, how strong the relationship is and if increasing residential density can be an effective tool for public transport promotion. The results indicate that increasing residential density could have an effect for public transport use only in neighbourhoods with lower density. Large part of the cities' population lives in prefabricated housing estates with high population density about 100 inhabitants per hectare. However there is no significantly effect, when the density is increasing above ca. 70 inh./ha. The results could be a contribution to the debate, under what conditions increasing residential density is an effective tool for creating sustainable city.

1. Introduction

Increasing population density is one of the most important tools for creating more sustainable city (Duany et al., 2010). On the other hand a compact city can be criticized for its lower liveability – quality of environment and well-being of people is often lower in such city (Neuman, 2005). It is necessary to achieve a balance between sustainability and liveability that is appropriate to a city of a particular size. People's expectations to healthy and pleasant environment will be naturally higher in smaller cities, where are however not so good economic opportunities (Glaeser, 2012). Furthermore it is much more important to protect green spaces and recreational areas in high-density neighbourhoods, where people do not have their own gardens. Thus social responsible planning should consider negative impacts of sustainable city forms to low-income groups of inhabitants, who live very often in high-density neighbourhoods.

This paper focuses on the relationship between public transport efficiency and population density in mid-size cities (about 100 000 inhabitants). This relationship is theoretically analysed on the basis of the concept of TOD (Transit Oriented Development), however it is necessary to adjust this concept to conditions of mid-size cities. We define following research question: How much does residential density affect public transport use in mid-size city? We try to find a threshold of residential density with a positive effect on public transport use. Such limit should be then accepted in practice for balancing demand for sustainable public transportation and demand for better availability of green spaces and recreational areas.

2. Literature review and research project

2.1 Literature review

During the last few decades we can observe an escalating debate about the urban design trends associated with the movement of New Urbanism, even in the Czech Republic. There is more talk about main themes of New Urbanism, i.e. the concept of compact city, walkable neighbourhoods, reducing car traffic, public spaces restoration etc. (Duany et al., 2010). One of the key themes of the new urbanism movement is the density of the city – population density, density of job places and facilities. Compact city with higher density is promoted as more sustainable urban form (Jenks et al., 2003).

An important group of scholars are concerned with specialized field of New Urbanism movements that focuses on increasing public transport efficiency. This concept is called transit oriented development (TOD). It should lead to more efficient use of public transport and it is based on analysis of the following parameters: Density of city, diversity (mixing use), design of city environment, distance to transit (distance to the nearest stop) and destination accessibility. The authors call these parameters as 5 D's of TOD (Cervero, Ewing, 2010).

Density is considered as important variable for TOD supportive city design. Very comprehensive research from R. Ewing, R. Pendall and D. Chen (2014) analysed 83 U.S. metropolitan areas with population over 500,000 inhabitants and concluded strong relationship between density and transit commute share. The literature review from Cervero, Ferrell and Murphy (2002, pg. 80) states following: "Research consistently shows that density has a significant bearing on transit ridership. In a 1995 Transit Cooperative Research Program (TCRP) study of boardings at 261 light rail stations across 19 U.S. and Canadian cities, an elasticity of nearly 0.60 was found between ridership and population density – controlling for other factors, every 10-percent increase in population density was associated with about a 6-percent increase in boardings at LRT stations."

But there are many sources that do not share the same level of enthusiasm. Even Jenks et al. (2003) in their flagship book regarding the concept of compact city (*The Compact City: A Sustainable Urban Form?*) critically evaluate the effect of higher density on travel behaviour. Their results indicate only a little effect of the urban form on transit commute share. Positive Cervero and Ewing's results were relativized by their own meta-analysis showing density has one of the weakest effect on transit use: "It is sometimes said that "mass transit needs 'mass'"; however, this is not supported by the low elasticities of transit use with respect to population and job densities..." (Cervero, Ewing, 2010, pg. 276).

Also there is a discussion, what is the residential density threshold for sustainable public transport system. It is talked about at least 7 units per acre (ca. 40 inhabitants/ha) for supporting bus service every 30 minutes and about 30 units per acre (170 inh./ha) for supporting bus service every 10 minutes (Cervero, 1993). R. Ewing (1999) sets lower value of 15 units per acre (85 inh./ha) for premium bus service. P. Hnilička (2012) sets the minimum of population density for economically sustainable bus service in Czech conditions on 50 inh./ha. Walkable city starts on 100 inh./ha.

It is obvious that different values will be relevant in smaller, mid-size cities. Most of researches concerning TOD focus on big cities or metropolitan areas. Jones, Mock and Cearley (2006, pg. 24) define the difference between travel behaviour in bigger and smaller cities as following: "In large metropolitan areas with well-utilized public transit systems, riders are more diverse in regard to socioeconomic status. However, in small to mid-size cities, riders tend to be predominantly poor and live in the innercity."

2.2 Research project

Our research analyses relationship between public transport use and the population density in three Czech mid-size cities with a population of 100 000 inhabitants. The purpose of this work is to contribute to the discussion, to what extent it is appropriate to apply the principles of the compact city in mid-size cities conditions. There are not such a good economic and career opportunities in these cities as in big metropolitan areas (Glaeser, 2012). On the other hand people in mid-size cities expect better environment and better access to public greenery. And the critics of compact city point out the "compact city paradox" – city with higher density could be more sustainable, but it is also less liveable (Neuman, 2005). Lot of people is still dreaming about living in more sprawled city, in houses with gardens or with access to free landscape and they are going to migrate to suburbia (Howley, 2009). So it is necessary to increase density only in that way that we would not discourage mid-size cities' inhabitants from living in a core city.

Our previous research has showed that access to free landscape, suitable for short-term recreation, could be in the Czech mid-size cities very unequal (Felcman, Franke, 2013; Felcman, 2014). There are big differences between individual neighbourhoods in their density. Over 3 million from a total 10 million people in Czech Republic live in prefabricated housing estates with high population density and this causes the inequality mentioned above. Implementation of compact city principles should not worsen the conditions of the people living in the housing estates, on the contrary, it should contribute to more social responsible planning of the cities. Identification of the residential density threshold will help to implement compact city principles in the appropriate neighbourhoods.

2.3 Research method

We collected data of public transport use from three Czech regional cities: Liberec, Czech Budejovice and Olomouc. The structure of the data was different. In Liberec and Olomouc we processed number of passengers using various public transport stops (number of getting on and off). There was available only occupancy of public transport vehicles between the stops in Czech Budejovice. In both cases we transformed the data in that way, we connected them with demographic data of individual basic administrative units (BAUs). According to their size of built-up area, number of inhabitants and population density we derived data of public transport use among individual BAUs.

Built-up areas of those cities contain contiguous area of settlement including connected settlements of neighbouring municipalities, without fragmented parts of built-up area. We used the method from previous research, where these central polygons were created (Felcman, Franke, 2013). Since we have focused on the housing areas only, we have eliminated those BAUs with less than 100 inhabitants. Also we eliminated those BAUs, which had more than 100 inhabitants, but their built-up area had mostly a non-housing character. According to land use plans those BAUs consist mostly of production areas, recreational areas etc. The population density of these BAUs was misrepresented, because most of their built-up area was not determined for housing. At the end we eliminated central parts of the cities – data of public transport use are misrepresented by high number of changing passengers in central parts, there is high mix of use and it could be expected that many residents do not use public transport and walk in these parts of the city (see fig. 1).

After this elimination we got into analysis 64 BAUs in Liberec, 44 in Olomouc and 36 in Czech Budejovice. We tested the relationship between the population density and public transport use index that is based on the ratio between the population and the use of public transport.

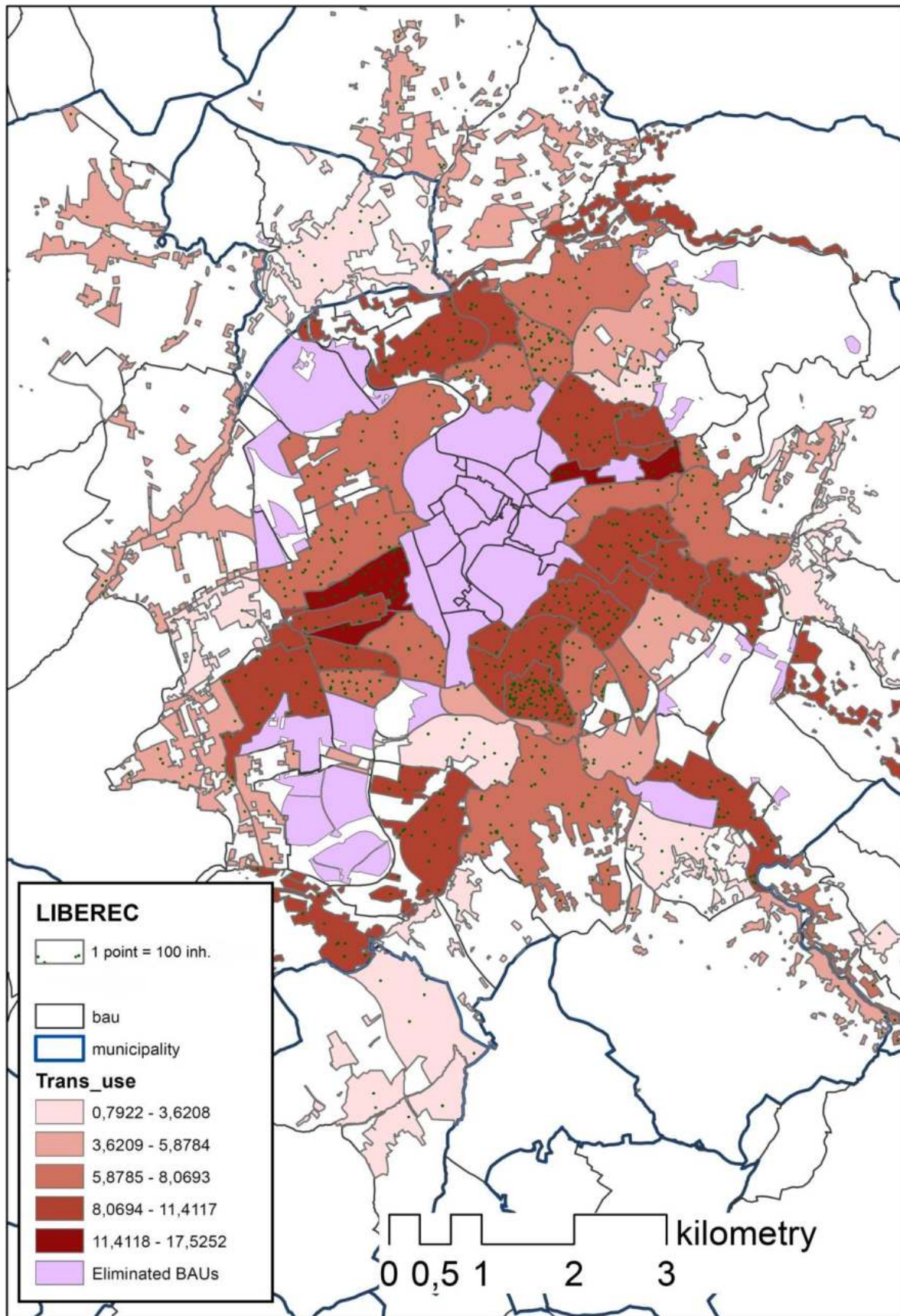


Figure 1. Results in Liberec – analysed BAUs without eliminated parts of the city (central parts, non-housing neighbourhoods).

2.4 *Statistic processing*

The goal of the statistical analysis was to establish statistically significant regression models for each city that would explain the use of public transport on the basis of population density in a given BAU. Then we focused on the appropriate adjustment of data and creation of a single set of data for regression analysis and the model of addiction between explained and the explanatory variable across cities.

The data of residential density and public transport use are available in three data sets distributed by town. The first step was the basic data editing, including compensation and reunification records in the data set to an initial value 0 and maximum value of index of public transport use around 18 for the planned unification of data. Followed by the basic statistical evaluation (e.g. to determine the median, standard deviation, skewness, kurtosis, etc.) and Shapiro-Wilk test was considered normality. Normality has not been proved; this has an impact on our conclusions that can be deduced from the statistical evaluation.

Variances hypothesis was tested for unified data for all three cities. The test showed equality of variances in relationship between public transport use and the residential density in all cities. The exception is the relationship of Liberec and Olomouc, where the hypothesis of equality of variances was not confirmed, but compliance was close.

Then we created 21 regression models with different settings and we selected the best four of them based on the most suitable parameters RMSE, R^2 and the test values characteristic “Pr > F”. We have chosen, if possible, a model where the value “Pr > F” indicates its significance.

All tests were confirmed at a significance level $\alpha = 0.05$ and as statistical software was used SAS in version 9.2.

2.5 *Results*

Czech Budejovice

Six models were constructed for the data from Czech Budejovice. The best values was showed by a model, which is defined by a second order polynomial levelling, and it achieves the coefficient of determination $R^2 = 0.22$. According to this model the use of public transport is indicated by population density from 22%. RMSE (Root Mean Squared Error) has also relatively low value of 3.3 in this model. Value “Pr > F” reaches 0.02, therefore the null hypothesis is not rejected and the model can be considered as significant. The functional relationship is shown in the formula below (y – use of public transport, x – population density):

$$y = -0,0009x^2 + 0,1508x - 0,8773$$

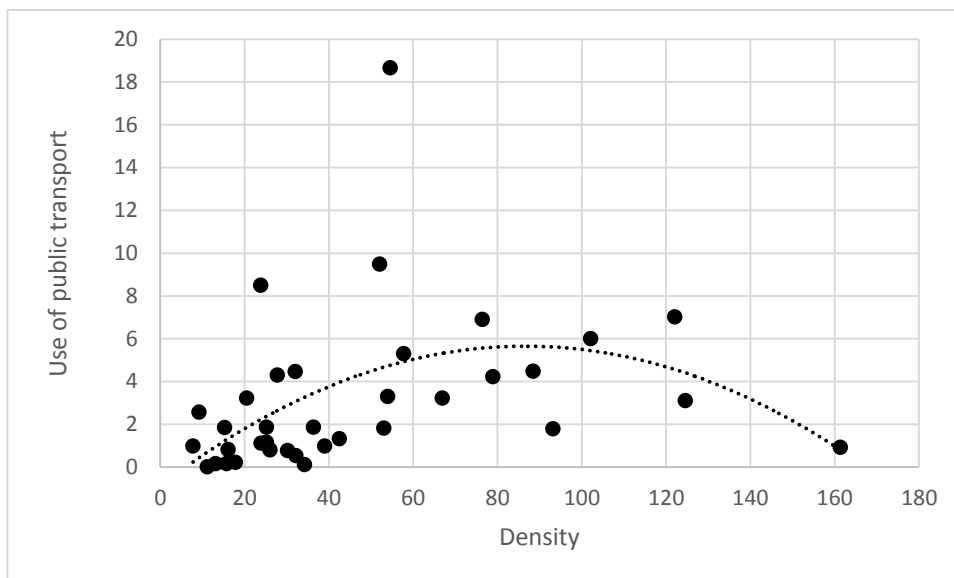


Figure 2. The relationship between residential density and public transport use in individual neighbourhoods in Czech Budejovice.

Liberec

The most appropriate model for Liberec was again selected on the basis of the best indicators value from six created models. The best values were showed by a model, which is defined by a third order polynomial levelling, and it achieves the coefficient of determination $R^2 = 0.357$. According to this model the use of public transport is indicated by population density from 35.7 %. RMSE showed by this model is also relatively low with value of 2.85. Value “Pr > F” is close to zero, therefore the null hypothesis is not rejected and the model can be considered as significant. The functional relationship is shown in the formula below (y – use of public transport, x – population density):

$$y = 0.00001x^3 - 0.0035x^2 + 0.2931x + 1,6529$$

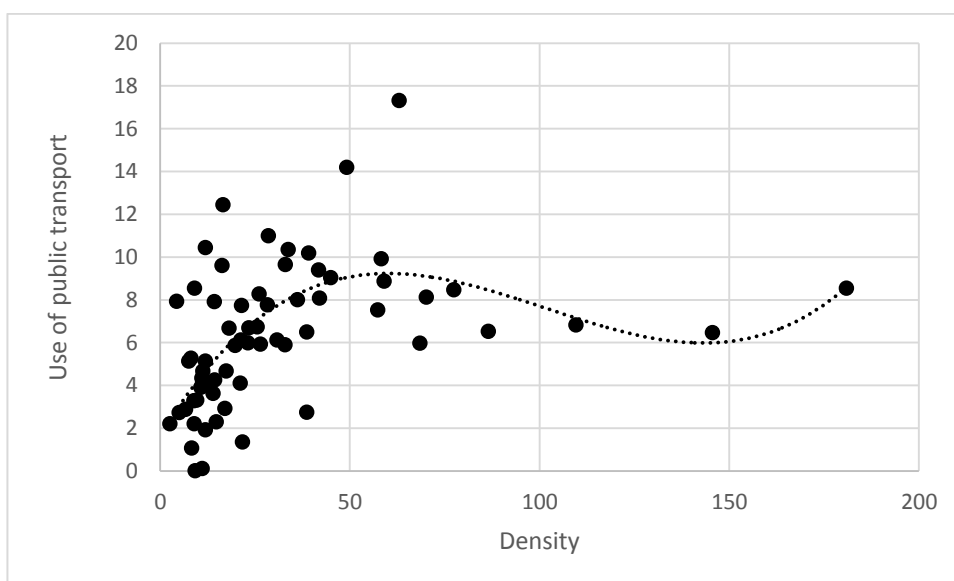


Figure 3. The relationship between residential density and public transport use in individual neighbourhoods in Liberec.

Olomouc

Six different regression models were created also for the city of Olomouc. None of them showed statistical significance. It can be chosen as the best second-order polynomial model from the available models that achieves a low coefficient of determination $R^2 = 0.06$. RMSE for this model reaches value of 3.6. Value “Pr > F” is very high (0.28) and therefore it is not statistically significant. For completeness, the following functional relationship designated by model below (y – use of public transport, x – population density):

$$y = -0,0002x^2 + 0,0495x + 3,9064$$

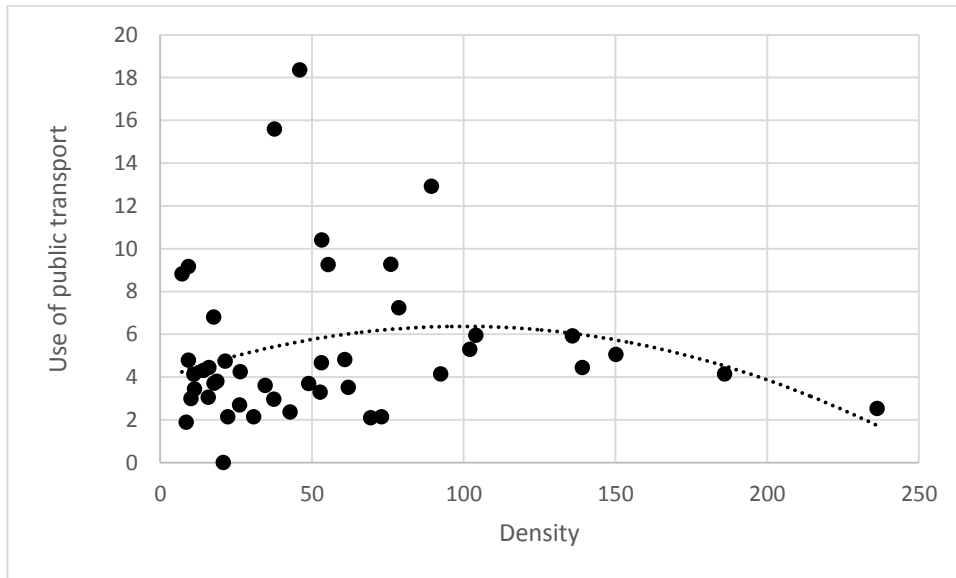


Figure 4. The relationship between residential density and public transport use in individual neighbourhoods in Olomouc.

The regression model for aggregated data from all analysed cities

Three models were created for aggregated data from all three cities. According to the indicators it was chosen model, which is defined by a third-order polynomial levelling. It achieves the coefficient of determination $R^2 = 0.1$. According to this model the use public transport is determined by population density from 10%. RMSE for this model reaches the value of 3.57. Value “Pr > F” is close to zero (0.0019) and therefore the model can be considered as significant. The functional relationship is shown in the formula below (y – use of public transport, x – population density):

$$y = 3E-06x^3 - 0,0012x^2 + 0,1335x + 2,5327$$

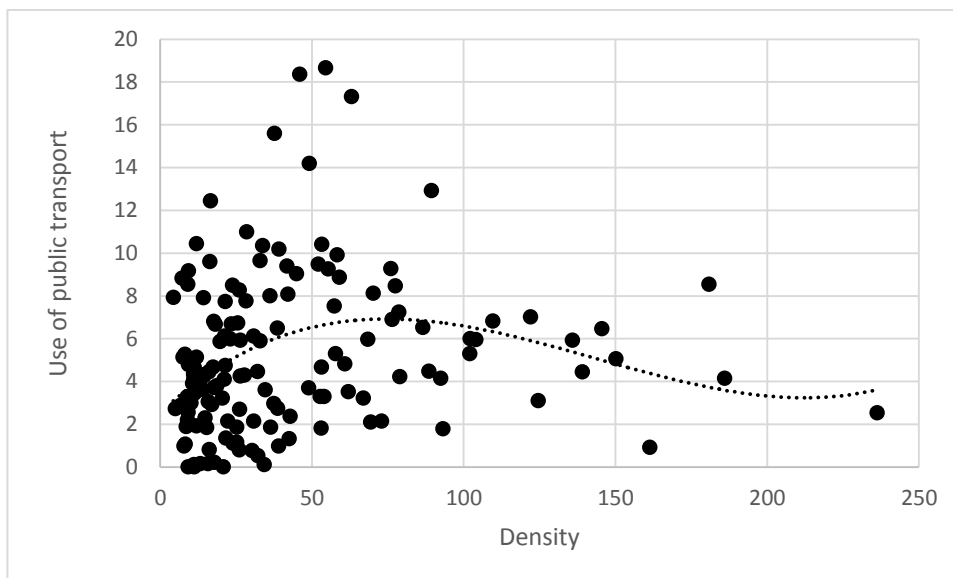


Figure 5. The relationship between residential density and public transport use in individual neighbourhoods of all three cities.

2.6 Discussion

Our study is limited by number of analysed cities and neighbourhoods. Furthermore the data of public transport use had different structure in all three cities and it was necessary to transform them. Only in Liberec we could analyse clear residential public transport use, because we had data derived by day time. So we made the analysis only with data of getting on passengers between 0:00 and 12:00 AM. It could be expected that those people are largely residents and not visitors and workers. The results could be more precise, if we could work with data of such structure from all cities.

The results are however quite similar in all three cities. We could observe that BAUs with density above ca. 70 inh./ha do not have significantly higher rate of public transport use in relative numbers (ratio of riders to number of inhabitants). The positive influence of increasing density is noted primarily in neighbourhoods with lower residential density. What could be consequences of such results?

At first we should mention that Czech mid-size cities are rather monocentric. People from peripheral areas make a large proportion of trips just to the central zones. All three cities have extraordinarily high numbers of passengers at stops in one central zone of a city. Also their system of public transport is concentric with one or couple of main transfer stops in central zone of a city. If we consider size of the urban area of the cities and distance between most of analysed neighbourhoods and central zones, we could not expect larger share of commuting by walk; the distance is largely more than 1 km. The monocentricity and the size of urban area together imply that principles of walkable city with residential density above 100 inh./ha (Hnilička, 2012) cannot be successfully applied in whole area of mid-size city. Such higher density could be appropriate in central zone, but there is no strong positive effect of such high density in peripheral neighbourhoods. On the contrary increasing residential density could decrease quality of environment in these neighbourhoods (Neuman, 2005).

Our previous research showed inequalities in free landscape accessibility in Czech mid-size cities. 64% of Liberec inhabitants live without direct contact with free landscape, although in Czech Budejovice it is only 37% (Felcman, 2014). In many cases development of new family houses cut off inhabitants of housing estates from free landscape in Liberec. Our results indicate now that

increasing residential density of those housing estates probably will not promote public transport use. Based on that, it could be recommended to protect green spaces close to prefabricated housing estates in Czech mid-size cities. Tools for increasing residential density should be targeted on neighbourhoods with lower density.

3 Conclusions

The results of our study indicate that increasing residential density positively affects public transport use rather in neighbourhoods with low density. Neighbourhoods with density above ca. 70 inh./ha – primarily prefabricated housing estates – do not have significantly higher rate of public transport use. We focused on Czech mid-size cities and we conclude that tools for increasing residential density should be targeted rather on neighbourhoods with lower density in these cities.

4 Acknowledgements

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