CHANGES IN THE TRAFFIC SITUATION ON CITY ROADS AFTER TRAFFIC DIVERSION OUTSIDE THE CITY

Norbert Mondek[1], Josef Bulíček[2]
University of Pardubice, Faculty of Transport Engineering, Studentská 95, CZ-53210 Pardubice, Czech Republic

Abstract: Road bypasses are constructed to mitigate traffic congestions in city areas. City roads are released and used by city and target traffic (with origin or destination in the city) primary. Travel time can be shortened for all. Question is how journeys within the city area will employ the infrastructure (city roads) originally used for diverted transit traffic. The aim of the article is to find out and to describe the impacts of traffic diversion in dependence on city size and importance of the city. Individual as well as public transport will be assessed, because bypassing has a different impact on each of them. Rerouting of a part of target journeys can be caused by bypassing in individual transport as well. Public transport service can be reduced with the aim to make connections (buses) transiting here faster. Research will be based on evaluation of a set of specific locations (bypassed cities).

Keywords: city bypass, road transport, traffic diversion, traffic flow.

1. Introduction

The article is focused on factors influencing the change in traffic volume on roads within city areas that are bypassed. Effects will be examined in relation to opening of city bypasses. The question is what factors determinate future traffic volume. There can be found examples of empty calmed roads (city roads) as well as of roads with significant traffic volume remaining there. Another important effect is that bus operators sometimes reroute their bus lines to faster or shorter bypass out of the city. Supply of public transport can be reduced in this way. The aim of the article is to find out and describe the impacts of traffic diversion in both modes in dependence on city size and importance of the city.
This article is a part of dissertation thesis, which is actually in process. The set of factors descripted in the article may not be final, but it can be extended in dissertation thesis. Topic of this article belongs to the soft systems. In spite of all attempts to maximize objectivity by the consideration of all factors and conditions in some cases may be quite opposite effects (e.g. small municipality is able to negotiate a full range of long-distance public transport). The aim of the article is to find common and expected effects in general and to learn from both positive and negative examples.

2. Literature Review

This chapter provides an overview about some of published methods and approaches. This analysis creates a background for appraisal of changes in the traffic situation on city roads after traffic diversion outside the city. The increasing automobilization of society is accompanied by negative impacts on society, which also includes increased noise disturbances to which inhabitants are exposed. The paper (Prekop et al., 2016) is focused on the ex-ante and ex-post evaluations of noise loads to inhabitants of the centre living along the former arterial route. The effort is to give a true picture of changes in noise loads to which inhabitants are exposed.
The locational shift in traffic can cause some existing businesses to close up or relocate, but it can also create some new business opportunities. The positive benefits of bypassing city centres commonly include the removal of heavy truck traffic from city centre and the opening up of additional industrial sites along the new route, thus attracting new investments from outside of the region. The negative impacts include increases in sprawled, low density commercial and residential development entailing high environmental and infrastructure costs. Economic impacts of freeway bypasses are presented in the paper Collins et al., (2000) for the cases of medium size cities (e.g. Danville (IL, USA), Richmond (VA, USA)).
Model for the analysis of traffic networks is provided by Peter et al., (2013). There is presented a domain level of optimal control for traffic networks applying Lyapunov function, and applying two level domain control on a realized network model of city Győr (Hungary). This model defines a unique structure of network elements and can be described map-graph independent by a special hyper matrix structure. Its main strength is the computing rapidity. The model can help by identification, where it will be effective to realize possible measures.
The paper Dzebo, (2018) presents a simplified model of traffic assignment to the planned bypass road. The purpose of such model is to provide to the planners a tool for simple, fast and inexpensive way to estimate the expected traffic volume on the planned bypass road by using data that can be obtained relatively quickly. Inputs of the model of traffic assignment are annual average daily traffic on the planned bypass and on the existing routes. Feasibility traffic studies of eight cities in Bosnia and Herzegovina were utilized as source of data.

3. Causes and Effects of Bypasses Construction

The basic question is simply – Why have been the bypasses built? The answer to the question can be found in the difficulties caused by the traffic in the city centre. The most common problems are increased travel times, exhausted capacities for inner city roads development, heavy traffic passing through the city centre and increased pollution, noise,

[1] Corresponding author: norbert.mondek@student.upce.cz

number of accidents etc. Aiming to resolve above mentioned problems is necessary for proper planning of city development providing optimal solution.
Effectiveness of city bypass can be assessed in two points of view. The first is about utilization of a newly constructed bypass itself. It is related especially to transit traffic passing in city. The appraisal is possible to be done by directional traffic census. The second question is what will be the change of traffic volume in the city. This second question is more complex. It is not about traffic volume only. Rerouting of traffic as well as trip generation problem causing induction of new traffic is taking a part in solution of this question as well.
Several hypotheses have been stated on the base of literature review. These hypotheses create the scope of the article:

- Bypasses do not necessarily result in a total reduction of total traffic volume in the city centre. Effectiveness of each individual bypass can be quite different in this point of view.
- Bypasses can have a significant impact on the development and location of retailing and local services.
- Public transport service in the bypassed city can be reduced with the aim to make connections (buses) transiting here faster.

4. Structure of Traffic Flows within the City Area

According to Ortúzar et al., (2001) there are 4 basic types of traffic flows in the city areas:

- transit flows passing the city,
- flows originating in the city and going to outlying areas (out of the city),
- flows coming from outlying areas with destination in the city,
- flows realized within the city area only.

Division transit flows can be added in the frame of discussion to this:

- transit in the main direction,
- transit between the main direction and other directions,
- transit in other directions.

This structure of traffic flows can be the base for estimation of city bypass importance and effectivity in general point of view. This analysis consisted of main positive and negative impacts in each type of flows is presented by following Table 1.

Table 1
Analysis of positive and negative impacts

Transit in the main direction	
+ bypass is usually in this direction + the most of transit will use diverted route	- calming of the city when this transit is dominant (economic viewpoint)
Transit between the main direction and other direction	
+ clamed roads within the city centre + possibility to minimize routes passing the city (by using of a part of bypass)	- bypass could be ineffective for this traffic volume - using of other roads in the city (in the case of "new" approach to bypass)
Transit in other directions and journeys within the city	
+ clamed roads within the city centre + bypass can be used only in some specific cases when it is copying part of the route	- using of the same roads as before
Journeys with origin or destination in the city, but going out or coming from out	
+ clamed roads within the city centre + possibility to minimize route through the city (by using of a part of bypass)	- bypass could be ineffective for this traffic volume - using of other roads in the city (in the case of "new" approach to bypass)

Source: authors

The result is that the bypass is attractive for driving in the main transit direction. Other drives can be more attractive due to traffic calming in city centre as well. This can be a problem, calming of transit routes can prepare possibility for traffic induction on other relations able to replace the diverted part of traffic flow.

5. Expected Factors in the Field of Road Traffic

This chapter is focused on introduction of a set of factors that are expected to impact traffic situation. Expected effects will be characterized. It is presupposed that these factors will be researched by mentioned dissertation theses.
City population (number of inhabitants)
The effect is related to the volume of originating traffic generated by city inhabitants. This can affect volume of origin traffic (production) and destination traffic (traffic attraction) as well. It is related to 2 facts:

- inhabitants start and finish their journeys in the city,
- volume of destination traffic should be related to the size of city as well.

Volume of transit traffic
It is important what is the share and volume of transit traffic in the area. The most of this traffic should be rerouted to city bypass (usually smoother drive, higher speed, minimal congestions). This traffic usually disappears within the city. On the other hand, in the case of small ratio of transit traffic it can cause ineffectivity of bypass. This relative small volume will represent prospected traffic volume on bypass.

Attractiveness of the city
This is subjective impact, but necessary to be considered. It is related to the fact if it is useful to come to the city itself or not. Tourism is typical example. On the other hand it should be related also e.g. to shopping possibilities etc. In short, this includes all reasons for travelling into city area.

Location of important objects in the city
This can affect selection of route in general way. It should be highlighted especially if there are objects generating high volumes of traffic like airports, large shopping or industrial areas. Specific is that these objects are usually connected directly to backbone network (motorway, bypass). This interconnection of objects to transport network is the main difference in comparison with the attractiveness of the city, because these objects are often strictly related to existence of this network. Attractiveness is especially related to traffic volume and location to traffic routing.

Attractiveness of bypass for trips within the city area
It may be effective to go between some places located within the city by bypass, especially when it is more quickly, shorter, more comfortable etc.

Comfort on bypass and bypassed route
Quality and comfort on both routes can be also important. This evaluation of routes is almost subjective. On the other hand, felling more safe and comfortable can sometimes cause change of selected route although selected route cannot be the shortest, the most quickly or the most effective. It can have impact in both cases – that the rout through the city will remain attractive as well as that the bypass will become attractive also for drives where it is not presupposed (it should lead to Braess paradox). Comfort can be also a problem in the case when bypass is not fully finished, during construction (reconstruction) works etc.

Extension of route in the case of bypass
The route using bypass can be sometimes longer in comparison with route within the city area. It could be illustrated by the case of Czech city of Mladá Boleslav, it was more effective to enter the city in Bezděčín then to use motorway D10 and its exit closer to the city centre.

Administrative measurements for traffic routing (traffic calming)
Powerful tool can be also administrative measurements supporting "expected" routing of traffic. Measurements can be divided into these 3 groups:

- interdiction of entry (incl. one-way street operation and interdiction of some types of vehicles),
- reduction of speed (effort to extent travel times = to decrease effectivity of route to be selected and used),
- supporting measures – like interdiction of parking.

Access fees
This includes parking fees and restricted city entrance with the aim to reduce number of vehicles in city centre. On the other hand also bypasses can be subject to a toll. This is negative to road users, which do not use regularly other tolled motorways. That is why the use of bypasses should not be favourable for all.

Spatial effects
Effect of road ascents and descents – should be important e.g. in mountainous areas. Possibilities of manoeuvres (dimensions of infrastructure) are second spatial effect – e.g. if road is suitable for freight vehicles etc.

Other possibilities to travel
Different impact should be in the city with quality public transport system, where volume of car trips should be lower than in the city with limited possibilities to travel in different way.

6. Possible factors in the field of public transport

Transport demand

- numbers of passengers travelling to/from the city,
- destination target of passengers is in one/multiple place,
- numbers of passengers transiting (continuing by the same bus),
- numbers of passengers interchanging to other public transport services in the city,
- time loss related to access of bus terminal in the city → possible to be modelled by using of system equilibrium (min. of average travel time).

Other effects

- Priority of line or of served relation (e.g. to connect important cities with no effort to serve bypassed).

- Concept of the transport system (possible effort to create hub in the city or not).
- Existence of other lines providing transport service for the city (e.g. in regional transport).
- Possibilities to create stops on bypasses (to save travel time for transiting passengers with possibility to serve the city).
- Existence of P+R concept (using multiple transport means).

7. Introduction of the Case Study

There were taken 8 cities located in the Czech Republic and 6 in the Slovak Republic into pilot consideration of mentioned effects. First of all, transport conditions are similar in both countries. For that reason, it is possible to put these data together for evaluation.

City categories

This article is focused on medium-sized cities. For application and appraisal of the factors is necessary to divide cities to three categories. Cities are divided from the point of view of regional importance (Table 2).

First category is composed of cities with transregional significance. These cities generate much origin (availability) and destination (attractiveness) routes as well as many routes have transit character. The cities in this category are operated by long-distance and regional public transport.

Table 2

City division to categories

Cat.	City	Bypass open	Bypass type	City type	City population	Long-distance lines service
1	Plzeň (CZ)	2006	motorway	transregional	170 936	all
	Olomouc (CZ)	2007	motorway	transregional	100 494	all
	Nitra (SK)	2011	motorway	transregional	77 048	all
2	Jihlava (CZ)	2008	1st class	regional	50 724	all
	Mladá Boleslav (CZ)	2015	1st class	regional	44 167	partly outside
	Kolín (CZ)	2012	1st class	regional	31 355	all
	Martin (SK)	2015	motorway	regional	62 738	partly outside
	Poprad (SK)	2009	1st class	regional	51 486	all
3	Chrudim (CZ)	2015	1st class	municipal	23 133	all
	Nymburk (CZ)	2010	1st class	municipal	15 062	all
	Vamberk (CZ)	2010	1st class	municipal	4 536	all
	Levoča (SK)	2015	motorway	municipal	14 803	partly outside
	Svidník (SK)	2010	motorway (half profile)	municipal	11 096	all
	Tornaľa (SK)	2006	motorway (half profile)	municipal	7 252	all

Source: authors on the base ČSÚ, (2018); ŠÚ SR, (2018)

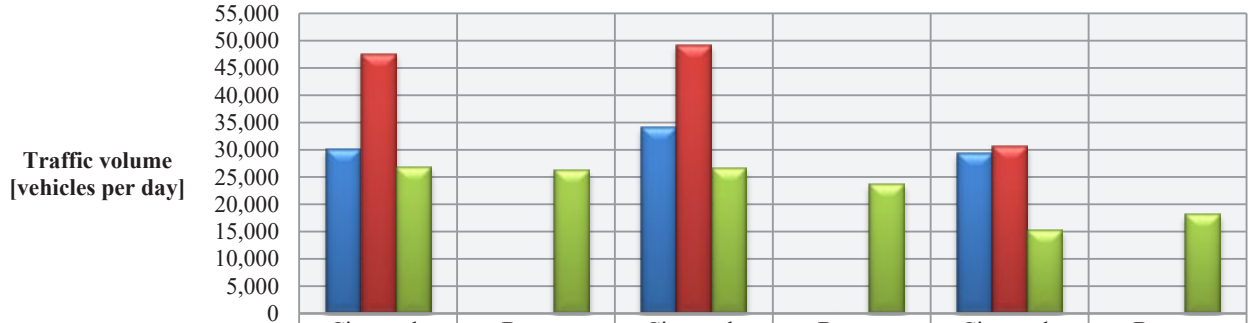
Second category includes cities with regional importance. These cities are mostly attractive for citizens from nearby and satellite city areas. Cities are operated mainly by regional public transport and also with most long-distance public transport. Only some long-distance buses (e.g. international connections) have higher significance and the cities are not served by them.

Cities with municipal importance are included in the last third category. There are cities with no attractiveness and the most of transport is composed of transit transport. For these cities is bypass the solution, which ensure transport calming in city centre and calming of the city in others viewpoint. Long-distance lines of public transport are not serving these cities, because they do not generate origin and destination routes for this transport mean. If the long-distance buses serve these cities, the reason is location of the city (and his bus terminal) directly on the route passing the city or the existence of major transport interchanges. If not, this service is lost.

These categories are represented by several Czech and Slovak cities. To comparison was chosen the cities, in which have built bypass in last 15 years. In the table are basic data about cities (number of inhabitants and city type). For categorization of the cities is necessary to analyse attractiveness of the city. It is subjective impact and as well it is specified by location of important objects in the city. The analysis was found, that in case of chosen cities is attractiveness proportionate to number of inhabitants. Finally, the cities were categorized based on presented data about cities and bypasses.

8. Impacts of Bypasses

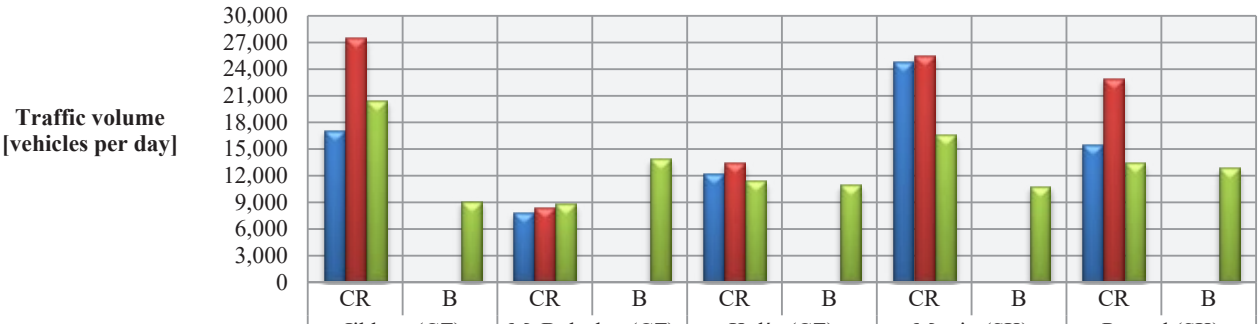
This chapter describes impacts of bypasses on selected set of cities. First pursued factor is volume of transit traffic. In all three city categories are observed similar results. After built the road bypasses are coming decrease traffic volume in city roads.
Specifically, in the cities from first category traffic volume was fallen by 50%. Current traffic volume is divided to city roads and bypass in a ratio of 1:1 (in typical case). City roads would be overloaded without bypasses as follows from this analysis. Growth of traffic volume in city roads (without bypass) would probably not be so great. The analysis confirms that bypasses do not necessarily result in a total reduction in total traffic volume in the city centre.
Fig. 1 confirms previous paragraph for first category cities. The data presents total traffic volume (all vehicles) in three levels. First is real traffic volume before bypass built. Second is estimated traffic volume (prognosis) on city roads after bypass built, based in prognosis published by national road authority (ŘSD, SSC). It is visible that the increase of traffic is more significant than it was presupposed. Third is real data after bypass built, which show decrease of traffic volume in city roads, but increase traffic volume on road bypass.



	Plzeň (CZ) 2000/2016		Olomouc (CZ) 2000/2016		Nitra (SK) 2010/2015	
	City roads	Bypass	City roads	Bypass	City roads	Bypass
Before bypass; Real data	30,107	0	34,217	0	29,355	0
After bypass; Estimated data	47,659	0	49,240	0	30,731	0
After bypass; Real data	26,815	26,274	26,677	23,681	15,331	18,272

Fig. 1.
First category cities traffic volume
Source: authors on the base ŘSD, (2001); ŘSD, (2017); SSC, (2011); SSC, (2016)

In terms of public transport there have been no changes. These cities are significant from the point of view of regional importance and they generate passengers traffic flows, thus it is not suitable to bypass them.
In the cities from second category is different situation between Czech and Slovak cities. Factually, in Poprad and Martin has come to decrease of traffic volume in city roads (CR) after bypass (B) built. In these cities were traffic volume fall by 40%. Total traffic volume in bypass and city roads is on the level of estimated data (Fig. 2).

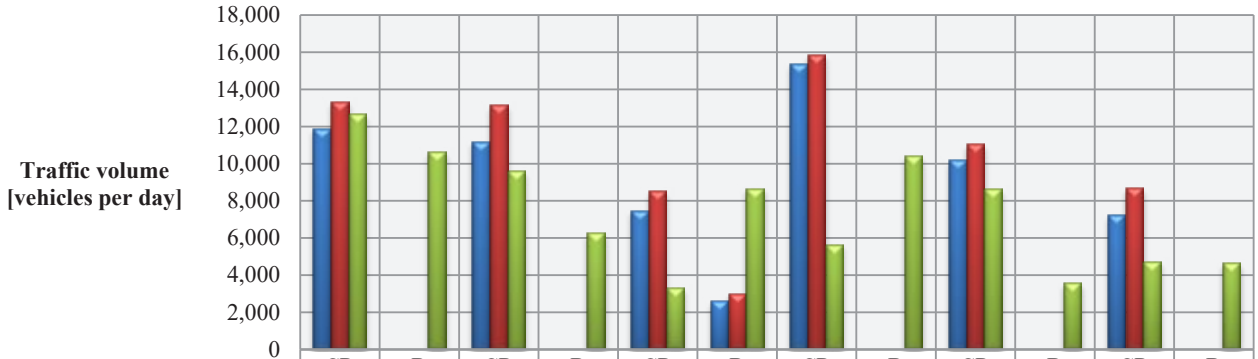


	Jihlava (CZ) 2005/2016		M. Boleslav (CZ) 2010/2016		Kolín (CZ) 2010/2016		Martin (SK) 2010/2015		Poprad (SK) 2005/2015	
	CR	B	CR	B	CR	B	CR	B	CR	B
Before bypass; Real data	17,099	0	7,762	0	12,194	0	24,756	0	15,526	0
After bypass; Estimated data	27,477	0	8,406	0	13,373	0	25,534	0	22,909	0
After bypass; Real data	20,450	9,085	8,778	13,873	11,410	10,922	16,598	10,765	13,413	12,880

Fig. 2.
Second category cities traffic volume
Source: authors on the base ŘSD, (2006); ŘSD, (2011); ŘSD, (2017); SSC, (2006); SSC, (2011); SSC, (2016)

In Czech cities were increase of traffic volume. In Mladá Boleslav and Kolín remained traffic volume in city roads on the level of estimated data. In addition to this is used road bypass by additional users. Total traffic volume increased more as twice. In Jihlava is situation similar to first category cities.

Changes in long-distance public transport occurred after building the bypasses. Some cities are not served by all lines, because servicing the cities is depended on character of bus lines. If bypassed second category city is located between higher cities, it is high probability to not serving the city by these buses. For example, Slovak city Martin is not served by long-distance buses, because more important is connection between Košice and Žilina in Slovakia. The same is valid for Mladá Boleslav, which is located between cities Praha and Liberec in Czech Republic.
In Slovak cities from third category after building the bypasses have been to traffic volume distribution to city roads (CR) and bypass (B). Traffic volume in these cities was not significantly increased. In Czech cities is different situation. The bypasses, alternatively empty city roads, attracted new road users to use the city roads. It did not cause expected decrease of traffic volume in city roads, but volume was decreased only slightly. Fig. 3 confirms this situation. Note to city Vamberk: This city has had built a part of bypass before 2000 and full bypass was open in 2010. From this reason are for this part of bypass mentioned real and estimated data before the full bypass was opened (Fig. 3).



	CR	B	CR	B	CR	B	CR	B	CR	B	CR	B
	Chrudim (CZ) 2010/2016		Nymburk (CZ) 2010/2016		Vamberk (CZ) 2000/2016		Levoča (SK) 2010/2015		Svidník (SK) 2010/2015		Tornaľa (SK) 2005/2015	
Before bypass; Real data	11,889	0	11,191	0	7,468	2,606	15,397	0	10,198	0	7,255	0
After bypass; Estimated data	13,347	0	13,138	0	8,513	2,970	15,881	0	11,045	0	8,678	0
After bypass; Real data	12,683	10,662	9,604	6,274	3,292	8,663	5,644	10,401	8,631	3,567	4,726	4,650

Fig. 3.
Third category cities traffic volume
Source: authors on the base ŘSD, (2001); ŘSD, (2011); ŘSD, (2017); SSC, (2006); SSC, (2011); SSC, (2016)

Increase of traffic volume is most probably brought by higher attractiveness of city routes because diverted transit traffic cleared the city roads after bypass built. Second factor of increase of traffic volume is bypass attractiveness, which was attracting road users from other lower category roads.
Selected cities have not high regional importance, but they are not located between higher cities (exception Levoča). From this reason they are served by long-distance bus lines in spite of bypass built. For example, there are two nearby cities in Czechia (Mirotice and Čimelice). City Mirotice (1 231 inhabitants) has bypass and many long-distance bus lines (27 from 28 between) are diverted outside the city. By contrast smaller city Čimelice (967 inhabitants) does not have bypass and it is served by 35% long-distance buses (10 from 28 per day). This suggests that the bus service of the city is dependent on more factors, not only on regional impact and bypass.

9. Distribution of Traffic Flows after Bypass Opening

It can be seen that 50.2% of traffic flows use city bypasses in average. Median value of 49.24% is close as well. It is in comparison with segments in city centres used for transit traffic in the past.
Basic overview is provided by Fig. 4 expressing relation between number of city inhabitants and ratio of traffic flows using bypass.
There is no significant relation between number of inhabitants and ratio of traffic using bypass. There is interesting fact that the maximally and minimally utilized bypasses are in the cities of the 3rd category. Maximally effective bypass is located in Vamberk (4 536 inhabitants) where 72.47% of vehicles using the bypass. Minimal ratio of traffic flow using bypass is registered in Svidník (11 096 inhabitants). It is the value of 29.24%.
Maximum ratio of 61.25% is registered in Mladá Boleslav (44 167 inhabitants) and minimal of 30.76% in Jihlava (50 724 inhabitants) in the case of 2nd category cities. Paradox is that both cities are very similar in the point of view of numbers of inhabitants to make such difference in result. It could be stated that structure of the city and regional area as well are very important for this. Mladá Boleslav is industrial centre. Connection of industrial plants to backbone communications (motorway) is relatively suitable that the vehicles coming here can use bypass as well. In the point of view of destination traffic the city of Mladá Boleslav has competition in the capital Prague (ca. 65 km far by motorway) and Liberec (ca. 51 km).

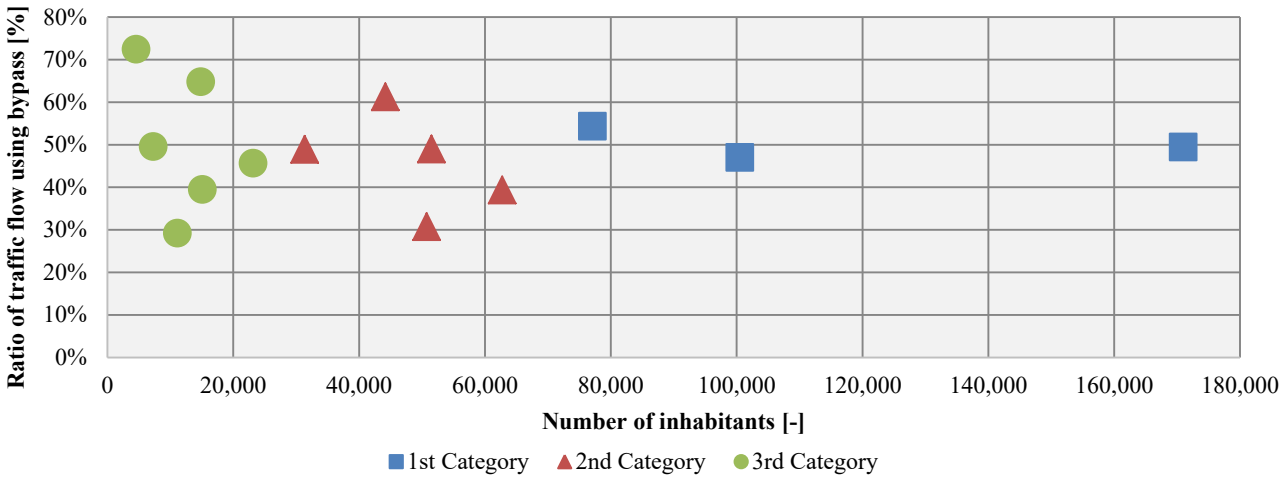


Fig. 4.
Relation between number of city inhabitants and ratio of traffic flows
Source: authors on the base ČSÚ, (2018); ŘSD, (2001); ŘSD, (2006); ŘSD, (2011); ŘSD, (2017); SSC, (2006); SSC, (2011); SSC, (2016); ŠÚ SR, (2018)

Jihlava is typical regional centre attractive to be a destination for traffic from surroundings. The distances are ca. 130 km to Prague and 90 km to Brno by motorway. Transit of passenger cars in direction south-north (along solved bypass) is presupposed to be not so significant due to these relatively longer distances. The places of possible destination can be distributed more evenly within the city area in comparison with the large industrial zone located in Mladá Boleslav. These facts can be explanation for this.
There are 3 cities examined in the first category. The result is that 47.03%–54.37% of vehicles use bypasses. The situation can be characterized as "average" in these cases.

10. Increase of Traffic Volume in Time

Development of traffic volume is measured in different time horizons in the most of cases. Identified difference in two measurements before and after bypass opening is averaged by time frame of 1 year and expressed as a percentage (ratio) of current volume of traffic flow.
The most important increase is registered in Mladá Boleslav. It is the value of 10.96% per year. There is about ca. 15 000 vehicles per day more in comparison of years 2016 and 2010. On contrary, minimal increase is registered in Levoča 0.81% per year. Average increase is 4.10%, median value of 2.99%. Median value is more illustrative because of relative high value in Mladá Boleslav.
Based on this case study, it could be simply quantified that it will take less than 25 years when the 50% of vehicles diverted to bypass (in average) will be substituted by newly occurred traffic (3% per year) in city centres. Naturally, this is a model case only. This process can be sometimes more quickly, sometimes more slowly according to local conditions. Traffic volume in city centre of Mladá Boleslav and Chrudim are higher than before bypassing after 6 years only. In the case of Jihlava after 11 years. Volume of traffic flows in Plzeň and in Kolín are about 90% of values before bypassing. In Plzeň after 16 years, in Kolín after 6 years.

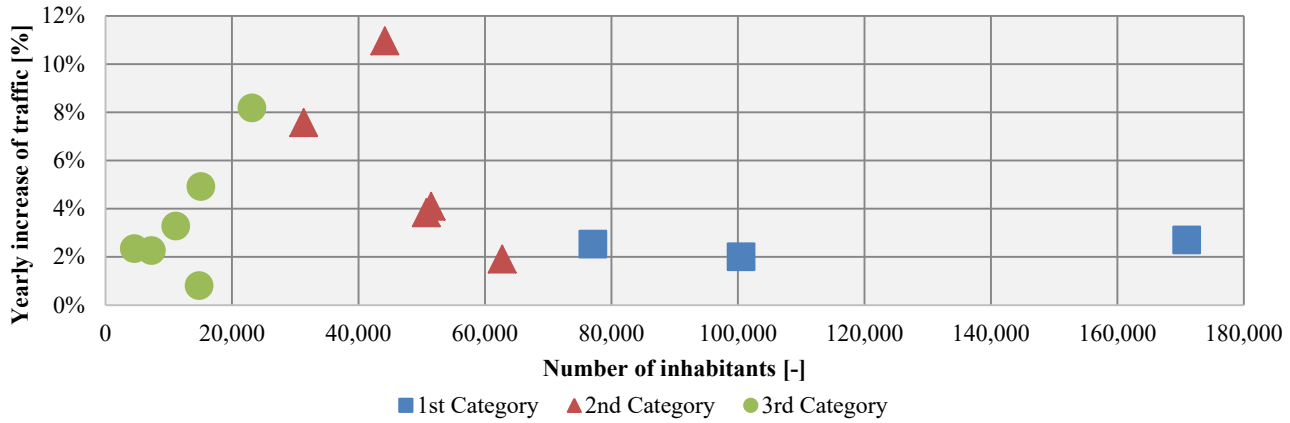


Fig. 5.
Relation between numbers of inhabitants and increase of traffic

Source: authors on the base ČSÚ, (2018); ŘSD, (2001); ŘSD, (2006); ŘSD, (2011); ŘSD, (2017); SSC, (2006); SSC, (2011); SSC, (2016); ŠÚ SR, (2018)

There is no significant relation between numbers of inhabitants and increase of traffic as it is illustrated by the Fig. 5. The reasons can be possibly caused by some socio-economic facts or by other effects.
On the other hand, it is correct to mention that traffic volume within city centres will be more and increased and serious without bypassing. Bypass can significantly slowdown the increase of traffic, this presumption is valid. Problem is with presumption that bypass will calm the traffic. This effect can occur in limited time only, because diverted traffic will be substituted if the volume of traffic will be still increasing like in time period of the beginning of 21st century evaluated in this article.

11. Following Research – Discussion

Results published in this article are based on a pilot study. It was shown by this case study that a lot questions are remaining in this filed. For example, effect of so called traffic induction was not evaluated separately within this study (it is considered within applied general numbers). Relations to some socio-economy data were not estimated. Common presumption (partial hypothesis) that number of inhabitants will have significant impact can be rejected now, after this basic study only.
There is a lot of space for future research what can be realized within elaboration of mentioned dissertation thesis.

12. Conclusion

The article confirms validity of all of the hypotheses stated in the chapter 4 of this article. In any case the building of bypasses help traffic situation in city centres. Traffic volume in city centres has not been totally reduced. A part of traffic was diverted outside the city by bypass, but it makes the possibility for new transport users to use the city roads. Only in some cities (e.g. Vamberk, Tornaľa) the traffic volume decreased and diverted transit traffic was not been replaced by new traffic.
Service of cities by long-distance public transport is partially dependent on road bypasses. It was confirmed that public transport service in bypassed cities can be reduced with aim to make bus connection faster between higher cities. Servicing the cities is also dependent on character of bus lines. It is a difference between cities in the same category, because some is located between higher cities (e.g. Mladá Boleslav) and some is itself the higher cities (e.g. Poprad).

References

Collins, M.; Weisbrod, G. 2000. Economic impact of freeway bypass routes in medium size cities. Available from Internet: <http://www.edrgroup.com/pdf/Urban-Freeway-Bypass-Case-Studies.pdf>.
ČSÚ – Czech Statistical Office. 2018. Počet obyvatel v obcích – k 1.1.2018 (Population in municipalities – 01/01/2018). Available from Internet: <https://www.czso.cz/csu/czso/pocet-obyvatel-v-obcich>.
Dzebo, S. 2018. The Regression Model for Assignment of Diverted Traffic to Planned Bypass Road. Available from Internet: <https://link.springer.com/chapter/10.1007/978-3-319-71321-2_62>.
Ortúzar, J.; Willumsen, L. 2001. *Modelling Transport*. Chichester: Wiley, 55–112, Third Edition. ISBN 13: 978-0-471-86110-2 (H/B).
Peter, T.; Bokor, J.; Strobl, A. 2013. Model for the analysis of traffic networks and traffic modelling of Győr. In *1st IFAC Workshop on Advances in Control and Automation Theory for Transportation Applications.* Available from Internet: <https://www.sciencedirect.com/science/article/pii/S1474667015352277>.
Prekop, M.; Dolejš, M. 2016. *Do bypass routes reduce noise disturbances in cities? Case study of Cheb (Western Bohemia, Czech Republic).* In *Geographia Technica*, 78–86. DOI: 10.21163/GT_2016.112.08. Available from Internet: <http://technicalgeography.org/pdf/2_2016/08_prekop.pdf>.
ŘSD ČR – Road and Motorway Directorate of the Czech Republic. 2001. Celostátní sčítání dopravy 2000 (Czech Traffic Census 2000). Available from Internet: <https://www.rsd.cz/doprava/scitani_2000/start.html>.
ŘSD ČR – Road and Motorway Directorate of the Czech Republic. 2006. Celostátní sčítání dopravy 2005 (Czech Traffic Census 2005). Available from Internet: <https://www.rsd.cz/vysledky-csd-2005/>.
ŘSD ČR – Road and Motorway Directorate of the Czech Republic. 2011. Celostátní sčítání dopravy 2010 (Czech Traffic Census 2010). Available from Internet: <http://scitani2010.rsd.cz/>.
ŘSD ČR – Road and Motorway Directorate of the Czech Republic. 2017. Celostátní sčítání dopravy 2016 (Czech Traffic Census 2016). Available from Internet: <http://scitani2016.rsd.cz/>.
SSC SR – Road Directorate of the Slovak Republic. 2006. Celoštátne sčítánie dopravy 2005 (Slovak Traffic Census 2005). Available from Internet: <http://www.ssc.sk/sk/cinnosti/rozvoj-cestnej-siete/dopravne-inzinierstvo/celostatne-scitanie-dopravy-v-roku-2005.ssc>.
SSC SR – Road Directorate of the Slovak Republic. 2011. Celoštátne sčítánie dopravy 2010 (Slovak Traffic Census 2010). Available from Internet: <http://www.ssc.sk/sk/cinnosti/rozvoj-cestnej-siete/dopravne-inzinierstvo/celostatne-scitanie-dopravy-v-roku-2010.ssc>.

SSC SR – Road Directorate of the Slovak Republic. 2016. Celoštátne sčítánie dopravy 2015 (Slovak Traffic Census 2015). Available from Internet: <http://www.ssc.sk/sk/cinnosti/rozvoj-cestnej-siete/dopravne-inzinierstvo/celostatne-scitanie-dopravy-v-roku-2015.ssc>.
ŠÚ SR – Slovak Republic Statistical Office. 2018. Počet obyvateľov v obciach – k 1.1.2018 (Population in municipalities – 01/01/2018). Available from Internet: <http://datacube.statistics.sk/#!/view/sk/VBD_DEM/om7101mr/Po%C4%8Det%20obyvate%C4%BEov%20pod%C4%BEa%20pohlavia%20-%20obce%20(mesa%C4%8Dne)%20%5Bom7101mr%5D>.