RELATION BETWEEN ROAD TRAFFIC INTENSITY AND URBAN DEVELOPMENT IN CITIES OF THE CZECH REPUBLIC

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Abstrakt

Příspěvek přibližuje posledních čtyřicet let ve vývoji cca 50 měst České republiky. Při stagnaci, či dokonce poklesu počtu obyvatel narůstají plochy bydlení., zvyšuje se intenzita silniční dopravy, a to jak osobních, tak i těžkých vozidel, motocyklová doprava ustupuje do pozadí s poklesem přibližně o více jak osmdesát procent. Vývoj měst je charakterizován funkčními plochami využití území z urbanistického hlediska. Jedná se o základní dělení na plochy bydlení, výrobní, rekreační, dopravní a ostatní. Tyto plochy byly vytvořeny analýzou s použitím územních plánů a leteckých měřických snímků z období mezi lety 1950 a současností. Intenzita silniční dopravy byla získána a zpracována z dat, která poskytuje ředitelství silnic a dálnic a jsou k dispozici od roku 1968. Článek ukazuje vztah mezi touto intenzitou, plochami využití a několika desítkami prostorových a a statistických hodnot, ukazuje vzájemnou závislost a shrnuje ty atributy, jejichž hodnoty mají největší vliv na intenzitu dopravy. Z výzkumu vyplynul seznam těchto atributů na jedné straně, ale na druhé straně to, že pro predikci vývoje je nutné vyhodnotit předcházející období daného města a z něj ji lze pak lze provádět. Analýza stavu v řadě měst v jednom období tuto možnost provést extrapolaci pro jedno město neposkytuje.

Abstract

The paper presents last forty years in urban development of several tens of the Czech Republic. Number of inhabitants has been stagnating or decreasing after 1990, however, residential areas and road traffic intensity have been increasing – both road traffic intensity of personal vehicles and trucks. Number of motorcycles has been significantly decreasing for approximately 80 per cent. The urban development is described by land use classes called urban functional classes. It is a basic classification to residential, productive, transport, recreational and other classes. These areas were created by an analysis of city plans and aerial photographs since 1950. The road traffic intensity was obtained from the Road and Motorway Directorate of the Czech Republic. The data have been measured since 1968. The paper presents relation between this intensity, functional classes and many others spatial and statistical attributes. It summarizes their influences and shows the attributes with the highest correlation and regression to the road traffic intensity. The result of the research shows the list of these attributes on one side, and the fact that it is an individual historical development of cities and the political and economical change in 1989, which must be taken into account for extrapolation of the road traffic intensity.

Klíčová slova: silnice, doprava, intenzita, land use, statistické data, GIS

Keywords: road, traffic, intensity, land use, statistical data, GIS

INTRODUCTION

It is nearly one third of the population (three million) in the Czech Republic, which is living in six cities with more than 100 thousand inhabitants – Prague, Brno, Ostrava, Plzeň, Liberec and Olomouc. The trend – increasing concentration of population of cities can be found in many countries in the world. It is a source of higher differences between rural and urban situations in their attributes and demands. Road traffic intensity is one of attributes with a severe impact to air condition, human health, etc. There are many projects and papers dedicated to the problem of road traffic intensity and its indicators and impacts. The book of Newman and Kenworthy (1989) compared 32 cities in 1960, 1970 and 1980. Barter and Kenworthy (1997) continued the previous book analysis processing 40 cities from five continents taking into account urban forms with their density and centers of activity (in jobs per hectare) reflecting their economical development. The other point of view in Barter and Kenworthy (1997) are transport patterns regarding passenger cars/1000 people, total vehicles/1000 people, road length/capita, road length/urban hectare, non-motorized % of work trips, etc. They show large differences among individual continents where American cities with their low-densities are one extreme and Asian cities are the other one due to a combination of many aspects including public transport. Authors of the The Transportation-Land Use Connection (2003) mention that design of land use areas affects the choice of mode of travel, however, the link between land use and transportation is extremely complex. Experiences from relation between transport and land use are presented for American cities in Moore, Thorsnes and Appleyard (2007) saying that communities that integrate transportation and land-use policies are better able to manage growth, improve the efficiency of travel. Litman (2012) takes into account influence of twelve land use factors as regional accessibility, density, land use mix, centeredness, road and path connectivity, roadway design, walking and cycling conditions, public transit service quality, parking supply and management, site design, mobility management and integrated smart growth programs.

This paper summarizes a part of Modeling of urban areas to lower negative influencies of human activities, COST project.

USED DATA AND THEIR PREPROCESSING

The data of the project had several independent sources. They can be grouped into three parts – data describing land use classes and other attribute city data, and road traffic intensity (measured as number of passing vehicles – trucks, personal vehicles and motorcycles).

GIS Land Use Data Processing

Twenty five cities of the Czech Republic were selected for the analyses in this paper. The cities differ in sizes, in economical orientation, in location in the country, etc. Statistical data about five land use functional classes (residential, productive, transport, recreation and other areas) were collected since 60-ies by the Statistical Institute and authorities of individual cities. The spatial data land use urban functional classes were derived from city plans and aerial photographs. The city plans were obtained from urban planning departments of individual cities in vector formats of various qualities. The aerial photographs were in two different forms. Historical aerial photographs (black and white) were scanned original photographs dated before 2000. Aerial photographs (RGB data) since 2000 were used by wms connection as seamless image data. Vector data from the Basic Base of Geographical Data (ZABAGED), Czech vector data in 1:10 000, were the source for accurate geographical information.

The first phase of the project was to create GIS data of the functional land use classes of individual cities. These functional classes were processed in six time levels – 1970, 1980, 1990, 1995, 2000, and 2010. The functional classes were formed from land use classes by their reclassification into the five resulting classes. The vector layers processing was based on GIS method. The first time level was the 2010 level. The final 2010 functional classes were derived from the city plans by the class delineation correction according to aerial photographs to exclude plans and apply the real state. The previous (2000) time level of each city functional classes was derived from its younger (2010) (already processed) level. This approach was repeated for 1990 (derived from 2000), 1980 data were derived from 1990 and 1970 from 1980 data. This method allowed ensuring correct topology of GIS layers.

Positional Attributes Definition and Calculation

New attributes called positional were defined. These attributes characterize position of cities from several different points of views. They describe connection of cities to regional cities, distance to expressway/motorway, and A-roads in these cities (**Table 1.**). These attributes were determined from GIS road network data. Correlation coefficients were calculated from relations of these attributes to road traffic intensity for all six time levels.

Tab 1. Positional attributes

1	Distance to the closest expressway/motorway
2	Percentage of roads connecting the city with a regional city
3	Percentage of roads connecting the city with the frontier
4	Percentage of A roads crossing the city

Statistical Data for Individual Cities

The other attributes were gained from the Czech Statistical Institute historical and present data, and from diploma theses of students of University of Economics.

To find relation between road traffic intensity and urban development, spatial land use characteristics and 35 statistic attributes were used. The final 35 attributes were selected from 414 originally available data. This lower attribute number was due to an incomplete set for processed cities in above-mentioned years.

Tab 2. Statistical attributes

Attributes		Group of attributes
1	Persons transported by public transportation	
2	Population /31.12./	Population
3	Births	
4	Deaths	
5	Immigrants	
6	Emigrants	
7	Total increase of population	
8	Male residents	
9	Female residents	
10	Population age 0 - 14	
11	Population age 15 - 64	
12	Population age 65 +	
13	Economically active population	Economic situation
14	Economically active males	
15	Economically active females	
16	People leaving for work	
17	People coming for work	
18	Diseases of the circulatory system	Diseases
19	Diseases of the respiratory system	
20	Diseases of the digestive system	
21	Injuries and poisoning	
22	Emission - sulphur dioxide - total amount	Emissions
23	Emission - sulphur dioxide - big sources	
24	Emission - carbon dioxide - total amount	
25	Emission - carbon dioxide - big sources	

26	Emission - solid - total amount	
27	Emission - solid - big sources	
28	Urban areas	Land use
29	Residential areas	
30	Production areas	
31	Traffic areas	
32	Recreational areas	
33	Other areas	
34	Other areas and barren soil	
35	Built-up core area	

Road Traffic Intensity Processing

The road traffic intensities were collected in 1968, 1973, 1980, 1990, 1995, 2000, 2005 and 2010. The data before 2000 were bought for the project from the Road and Motorway Directorate and the data since 2000 are available on the Directorate web page.

Road traffic intensities are measured in predetermined points in the Czech Republic road network which is not the same in above mentioned time level measurements. Their number varies for individual cities; these intensities are collected in higher number of points in larger cities. To overcome time and cities difference, new intensity values were defined. Average road traffic intensity (ARTI) was calculated as an average value of all measured intensities (trucks, personal vehicles, motorcycles and their sum) in individual cities. ARTI characterized internal average road intensity in cities. Maximum road traffic intensity (MRTI) was determined as a sum of all intensities measured on roads entering individual cities. MRTI described number of vehicles coming to individual cities regardless their reason – the city is their terminal target or they just pass through.

METHODOLOGY OF ROAD TRAFFIC MODELLING USING SPATIAL AND STATISTICAL ATTRIBUTES

Two approaches were used. The first one was calculation of correlation coefficients between ARTI/MRTI and individual attributes. The second one was Multiple linear regression (MLR) calculated using Statistical Package for the Social Sciences.

Correlation Between Average and Maximum Road Traffic Intensiti**es**

Microsoft Excel provides useful statistical functions for measuring correlation between two variables. The CORREL function is one of them. This function determines whether two data sets are related, and if so, how strongly. The correlation is expressed as a “coefficient”. The correlation coefficient (further as CC) is scaled so that its value is independent of the units in which the two measurement variables are expressed. The value of any CC ranges from +1, indicating a perfect positive linear relationship, to -1, indicating a perfectly negative linear relationship.

Correlation coefficients (CC) were calculated in two ways. Individual correlation coefficients for individual cities for two periods: 1970 – 1990 and 1970 - 2010, where one value of the CC for each attribute for the whole period was calculated, and 1970 – 2010 where values of the CC for each attribute in every year (1970, 1980, …) and values of the CC for each attribute in every town were calculated. Two periods were used since it was found that development in two different political and economical conditions substantially differed. (Stolbenková, 2012). Number of personal vehicle increased enormously under the new economical situation after 1990. Many new natural and legal persons were established and their new economical role brought higher demand primarily for personal vehicles. The growth of personal vehicles between 1970 a 2005 was from 64 to 373 personal vehicles per 1000 inhabitants (Plůcha 2007, Telcl 2007); the increase was for 52 vehicles/1000 inhabitants in the 1980-90 period and for 149 vehicles/1000 inhabitants in 1995-2005.

Multiple linear regression

MLR can model the linear relationship between a dependent variable and more than one explanatory (independent) variables. The mathematical formula applied to the explanatory variables to best explain or predict the dependent variable is following:

$$y = b_0 + b_1.x_1 + b_2.x_2 + ...b_n.x_n + \epsilon$$

x_i explanatory variables
β_I regression coefficients
ε residual

Spatial and statistical attributes were used as explanatory variables and the road traffic intensity was the dependent variable (y).

The MLR was performed for every year 1970, 1980, 1990, 1995, 2000 and 2005 and for three sets of years from 1970-1980-1990, 1995-2000-2005 and 2000-2005 (Stolbenková 2012).

RESULTS

Correlation Between Average and Maximum Road Traffic Intensities

Included attributes describe an issue of population, land use and public transportation in correlation between an attribute and the ARTI/MRTI for the 1970–2005 period. Although, land use attributes miss values for the year 1995 and they are not complete in following years, too. In both cases (**Table 2 a, b**), moderate, weak and very weak relationship occurs. At the first sight, the MRTI seems to be related to the chosen attributes more than the ARTI. The values are a little higher and there are more of the moderate correlations (>0,5). Built-up core[1] area and Population aged 15-64 belong among the most significant attributes. Moreover in the case of the MRTI, attributes such as Population /31.12/, Female and male residents, Emigrants and Deaths seem to be important as well.

Tab 2. a, b. 8 highest correlations between 8 attributes and ARTI (a- left)/ MRTI (b - right) in 1970–2005

Correlation between attributes and ARTI in 1970 - 2005	
Attribute	CC
Other areas and barren soil	0,5600
Built-up core area	0,5548
Population aged 15-64	0,5135
Emigrants	0,4750
Population (31.12)	0,4609
Female residents	0,4509
Male residents	0,4476
Recreational areas	0,4449

Correlation between attributes and MRTI in 1970 - 2005	
Attribute	CC
Other areas and barren soil	0,6445
Built-up core area	0,6353
Population aged 15-64	0,6314
Population (31.12)	0,5807
Female residents	0,5781
Emigrants	0,5749
Male residents	0,5731
Deaths	0,5341

Within the analysis of correlation between an attribute and the ARTI/MRTI for the 1970–1990 period of three-phase development, more results can be seen (**Table 3 a, b**). Apart from attributes of population, land use and public transportation, also attributes of economic situation and emissions are involved. Again, the correlation with the MRTI exhibits significantly higher values than the correlation with the ARTI does.

[1] Core-built areas are built-up areas of cities before joining neighbouring village in 70-ies and 80-ies

Furthermore, nine variables show strong relationship to the MRTI. The most important attributes related to the ARTI are Built-up core area, Other areas and barren soil and Recreational areas.

Tab 3. a, b. 9 highest correlation between attributes and ARTI (a - left)/MRTI (b - right) in 1970-1990

Correlation between attributes and ARTI In 1970 - 1990		**Correlation between attributes and MRTI In 1970 - 1990**	
Built-up core area	0,6349	Population 65+	0,7294
Other areas and barren soil	0,6059	Other areas and barren soil	0,7228
Recreational areas	0,5676	Population (31.12.)	0,7195
Traffic areas	0,5368	Female resident	0,7187
Economically active females	0,5304	Deaths	0,7158
Emigrants	0,5303	Male residents	0,7125
Residential areas	0,5273	Population aged 15 -64	0,7108
Population (31.12.)	0,5155	Built-up core areas	0,7099
Deaths	0,5078	Emigrants	0,7015

This analysis of correlation between an attribute and the ARTI/MRTI in the 1970–2005 period introduces a value of the CC for an attribute in each of the six years. **Table 4** presents very strong relationships that can be found at four land use attributes, the highest at Traffic areas in 2005 for the MRTI. Also distinctly more values of strong correlation are apparent in the part related to the MRTI.

The analysis of correlation between an attribute and the ARTI in individual cities presents calculated values of the CC for each attribute in every town (**Table 5**). However, these results are not so reliable and trustful because of the incomplete values. The situation varies in every town. It is important to mention that almost every attribute reaches low as well as high value of the CC; **Table 5** shows an example of three cities with their three highest CC.

Tab 4. Correlation coefficients between attributes and the MRTI for each year in the 1970 – 2005 period

	1970	**1980**	**1990**	**1995**	**2000**	**2005**
Public transportation	0,5771	0,6411	0,6388	0,7636	0,4388	0,7049
Residential areas	0,5676	0,6262	0,5949	--	0,9535	0,7519
Urban areas	0,6313	0,5758	0,5298	--	0,9322	0,8022
Recreational areas	0,5980	0,5615	0,6949	--	0,8107	0,8002
Traffic areas	0,6408	0,6192	0,7753	--	0,7246	0,9139

Tab 5. Correlation between attributes and the ARTI for towns in the period 1970 – 2005

Brno	**CC**	**České Budějovice**	**CC**	**Hradec Králové**	**CC**
Population aged 15-64	0,9321	Urban areas	0,8450	People leav. for work	0,9996
Public transportation	0,8249	Population aged 15-64	0,8255	Residential areas	0,7739
Emigrants	0,5702	Recreational areas	0,8249	Population aged 15-64	0,7154

Multiple linear regression

The MLR was performed for every year 1970, 1980, 1990, 1995, 2000 and 2005 (ARTI see **Table 6 a**, MRTI see **Table 7**) and for three sets of years from 1970-1980-1990, 1995-2000-2005 and 2000-2005 (ARTI see **Table 6 b**, MRTI **Table 7**). It was searched for statistically significant predictors of the dependent variable (the ARTI or the MRTI), it means that explanatory variables that are less than 0,05 to be considered significant or meaning full reliable.

Tab 6. a. Models explaining ARTI in individual years; R^2 shows percentage of the variability of ARTI – dependent value

Year	R^2 [%]	Attribute types	Explaining variables
1970	15,3	P+E+L	Population
1980	47,4	P+E+L	Population Recreational areas
1990	53,6	P+E+L	Population Recreational areas
1995	80,4	P	Population aged 0-14 Immigrants
2000	47,3	P	Population Population aged 0-14
2005	60,4	P	Population Population aged 0-14
2005	99,1	P+L	Population Population aged 0-14 Female residents Total population growth Traffic areas

P = population attribute group, E = economic situation attribute group, L= land use attribute group
Opposite contribution

Tab 6. b. Models explaining ARTI in periods; R^2 shows percentage of the variability of ARTI – dependent value

Year	R^2 [%]	Attribute types	Explaining variables
70-80-90	49,0	P+E+L	Population Births Economically act. Population Recreational areas
95-00-05	60,3	P	Population Population aged 0-14
00-05	94,2	P+L	Population Population aged 0-14 Total population growth Traffic areas

P = population attribute group, E = economic situation attribute group, L= land use attribute group
Opposite contribution

Tab 7. Models explaining MRTI; R^2 shows percentage of the variability of ARTI – dependent value

Year	R^2 [%]	Attribute types	Explaining variables
1970	42,8	P+E+L	Population
1980	69,6	P+E+L	Population Total population growth
1990	75,7	P+E+L	Population Population aged 15-64 Recreational areas
1995	84,7	P	Population Population aged 15-64
2000	60,7	P	Population Total population growth
2005	59,1	P	Population
2005	95,6	P+L	M/F residents Traffic areas

P = population attribute group, E = economic situation attribute group, L= land use attribute group
Opposite contribution

70-80-90	48,1	P+E+L	Population

			Economically act. female Recreational areas
95-00-05	66,6	P	Population Population aged 15-64
00-05	80,8	P+L	Population Population aged 15-64 Traffic areas

CONCUSION

The purpose of the project was to analyse various indicator influences on the road traffic in GIS. The analysis covered the development in 25 towns in the Czech Republic during the period from 1970 to 2005. The analysis was based on the existing data of both average and maximum road traffic intensity (ARTI and MRTI) and on town position, collected statistical data and spatial land use development and changes. The process of displaying, analysing and examining the road traffic intensity and the given statistical data showed that the period after the year 1990 proved a significant change in the development and behaviour of the variables. The possible original cause could have been found in the history of the Czech Republic and individual cities. The communist regime had had a big impact on everything that happened in the country during the 70-ies and 80-ies. And finally, the analyses were also divided into two periods – one from 1970 to 1990 and the other from 1995 to 2005.

Viewing values of spatial positions of cities, all criteria were found important and revealing. Except for the situation on an A-road, which was moderately misleading. The situation seems to be very similar for both ARTI, and MRTI. However, ARTI might be related to the situation on a connecting line to regional towns and on an international road more than the MRTI. On the contrary, the MRTI has higher dependence on the distance from motorways and expressways. Examining the motorway/expressway development, the ARTI seems to be related to this criterion in seven towns, whereas the MRTI in eight towns. The ARTI might have increased due to building a motorway/expressway in Frýdek-Místek, Jablonec nad Nisou, Liberec, Mělník and Plzeň; the MRTI in the same towns plus Kutná Hora and Ústí nad Labem. ARTI might have decreased due to building a motorway/expressway in Cheb and Ústí nad Labem; concerning the MRTI, only in Cheb. In other towns, the ARTI seemed to behave independently from the motorway and expressway development.

Viewing the correlation coefficients in each year, very strong relationships were found out in attributes Traffic areas and Recreational areas in 2005 for the ARTI, however, only in Traffic areas in 2005 for the MRTI. Moreover, Built-up core area and all population attributes except for Total population growth were predominantly strongly related to the MRTI. Also diseases attributes reached strong values. People coming for work might have been another important variable, which reached strong correlation with the ARTI and the MRTI in 1990. The emission attributes showed a rather weak relationship with the RTI.

Viewing the situation in each town, among the most frequently occurring attributes of the highest value of the correlation coefficient ranged People leaving for work, Other areas, Urban areas and Residential areas for the ARTI and People leaving for work, Recreational areas and Residential areas for the MRTI. Categorizing the towns into groups, according to the type of attributes that showed a very strong value of the correlation coefficient, the combination of population and land use attributes may be related to the development of the road traffic intensity the most.

Finally, performing the multiple linear regression showed for both the ARTI, and the MRTI that the most statistically significant and important variables might be almost the same. Generally speaking, in the period from 1970 to 1990 the road traffic intensity could be partly explained through the variables of Population, Recreational areas and Economically active population or females. However, in the period from 1995 to 2005 the road traffic intensity can be defined by variables of Population, Population aged 0-14, Total population growth and Traffic areas.

To sum up, all analysed factors seemed to indicate a relationship to the road traffic intensity. Concerning the statistical and land use attributes, it would be useful to gain further values. The values were insufficient for land use variables in the years 2000 and 2005, for the economic situation for the period 1995 – 2005 and for emissions in 1970, 2000 and 2005. The data about diseases were available only for the year 1995. Results from correlation calculations and MLR models were a little different. The multiple linear regression models gave higher importance to variables that showed lower correlation computed in the Microsoft Excel software and vice versa. That happened because the multiple linear regression takes into account combination of these variables to predict the outcome. This is the contribution of each variable but only in combination with each other.

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