# Models of 40-Year Spatial Development of Cities in the Czech Republic in a geographic information system

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***Abstract*—There are many indicators of sustainable development of towns defined by urban specialists, sociologists, economists, etc. The paper presents the first part of a project whose goal is to find indicators of harmonic development of towns based on analysis of forty years development of fifty Czech towns. The indicators are studied in land use spatial changes, demography and road traffic intensity changes. First ten towns were processed for the period between 1970 and 2009 being mapped in general urban land use classes and related to the measured road density. City land use class areas were derived from combination of actual and historical city plans and remote sensing data using geographic information system tools. It was found that the traffic intensity within towns and to and from towns is more dependent on existence of close highways and by-pass roads unlike number of inhabitants, e.g. Political changes from the communist regime to the democratic one was also an important breakpoint in the city developments. Increase of the road traffic intensity and enlarging of residential areas are features proving the fact. The paper presents a methodology of spatial mapping of land use classes utilized for determination of town development. The city developments and their relation to road traffic are documented on maps and graphs.**

***Keywords-GIS; remote sensing data; city plan; number of inhabitants; urban model; land use; road traffic intensity***

## I. INTRODUCTION

The development of cities during last decades has faced us with a new situation. Most inhabitants in many European countries are concentrated in large towns. One fifth of the Czech Republic population is living in three largest towns – Prague, Brno and Ostrava. Fig. 1 shows percentage of inhabitants of all analyzed cities compared to two largest cities of the country- Prague and Brno - forming nearly half of inhabitants; therefore, the results of the analysis can be regarded as really representative.

Present state of the balance among consumption level of society and quality of life is a matter of scientific papers, research [2][5][6], many projects [1][7], and political and economical discussions in many countries. Life quality is directly related to a lot of environmental and socio-economic conditions. These conditions determine a harmonic development which should be based on equivalent and adequate demands of the human society. To define "adequate" means to take into account both consumption, and quality of life. Both are closely connected to the road traffic and its intensity.

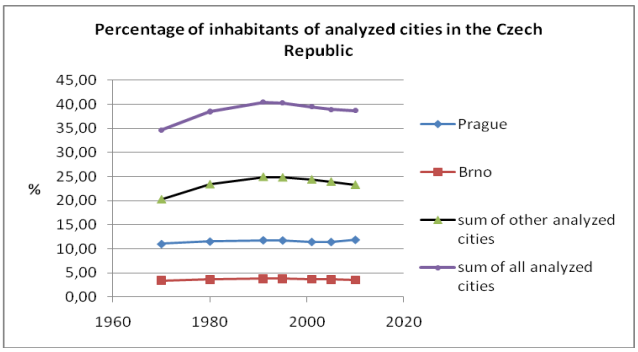


Figure 1. Development of percentage of inhabitants of analyzed cities in the framework of the Czech Republic

The Department of Mapping and Cartography has been processing a COST project focused on a detailed evaluation of relations between the quality of life and present behavior of the human society. The project goal is to create a model allowing improving the present development status in urban areas being less demanding and ensuring their sustainable development.

The project is a logical continuation of several projects performed by specialists from the Czech Technical University (CTU) in Prague in the Czech Republic and the State Institute for Regional Planning who have collected and summarized large data volume of fifty towns (including three largest ones - Prague, Brno and Ostrava) on:

1. Functional typology comprising five general land use classes: housing and infrastructure areas summarized into a residential one, industrial and agricultural production areas named areas of production, areas of traffic, areas of recreation including sport and green vegetation land, surface water areas, etc., and areas of other functions like arable land, orchards, meadows, technical infrastructure – waste water treatment plant areas, quarries, e.g., this classification is used by urban planners and the individual city land use maps utilize its list.
2. The second group of land use has been collected and recorded by the Czech Office for Surveying,

Mapping and Cadastre (COSMC) and Czech Statistical Office and consists of urban, agriculture, forest and water surface areas and other function areas. The data are related to 1970, 1980, 1990, 2000, 2005, and 2008.

3. Basic components of the environment.
4. Basic components of the social and economical development.

The last two groups of data were collected within many diploma theses for individual cities as the statistical data were recorded for districts only.

The previous projects were focused on statistical data collected from the above mentioned sources and their processing. They did not comprise any spatial data and no spatial analyses were performed. Their city collection resulted in a large range of cities differing by population (from seventeen thousand to more than one million inhabitants), by economic orientation (agricultural, industrial, university, touristic), by natural conditions (lowland surrounded by agricultural areas, mountainous situated large forest areas), by geographic position in the republic – close/far to a frontier, etc. The city set is a good sample covering practically all Czech city types.

The processed project is focused on two new views – to select suitable indicators of the sustainable city development in the Czech Republic using also spatial characteristics together with already collected ones, and the role of the road traffic intensity in the development of cities and their mutual relation and impacts.

Individual land use areas offer different conditions for living. The same land use classes in different areas and therefore all spatial units are characterized by a long list of attributes.

## II. CZECH CITIES AND THEIR DEVELOPMENT

The Czech Republic does not have a continuous political and urban development. The development was formed mainly by political decisions having a decisive role of the urban land use changes. After the Second World War the urban development was relatively uneven and can be characterized by three types of cities. One type of cities had only a relatively slow and continuous spatial evolution within their administrative boundaries. The second type are cities with growing administrative areas; however, this growth was artificial as a result of political decisions to join surrounding villages to a close city. This joining was in two phases in 70-ies and 1989. The third group of towns is similar to the second one; the only difference is in their further separation of one or more early joined villages. The separations occurred after changing of the political regime in the country at the end of 1989 from the communist to the democratic regime. This development definition was firstly described and denoted by Vepřek [8]. He uses three new terms: core area for town size representing in most cases a status in 70-ies of the 20$^{th}$ century (1974, 1976). These were years when the process of joining villages to neighbor cities became an important phenomenon in administrative structure of the country. The joined areas are named associated areas by Vepřek in [8]. Urban parts in associated regions are denoted agglomerated ones by Vepřek in [8]. The parts, which became independent villages, are called peripheral areas by Vepřek in [8].

These spatial developments is archived in Cadastre books in the form of table records showing concerned cadastre districts and also in COSMC data available on its portal as excel files. The transfer of this information into spatial data can show the spatial city development using the cadastre districts´ boundaries of an appropriate period. This transfer was performed also into city plans, whose processing intervals vary in individual towns. City size evolutions cannot be derived from remote sensing data. If a town belongs to the second or third group, there are large spatial changes. The largest parts of these changes are in prevailing part represented by agricultural areas. The main difference between a core area and associated area are separated urban parts occurring in them.

## III. LAND USE MAPS

The forty years spatial development is characterized (in the project) by land use maps of functional classes in 2009, 2000, 1990, 1980 and 1970. High number of cities covering large areas demanded to use time effective method for their mapping. Their creation was based on adaptation of city plans, remote sensing and statistical data.

Each urban area has a city plan as given by the Czech Law. Land use class determinations were done from land use classes applied by urban engineers in city plans which have been processed in several-year periods differently in individual cities. Therefore the city plans were the first information layer for urban land use maps processing. The plans comprise maps of the current land use/cover state and proposals for the future development and it was necessary to separate the urban plans. The process started by creation of the latest year map and ended by the 1970 land use map.

### *A. Determination of Land Use Classes*

The first step of creating of the first time level of each land use map was a reclassification of the original city plan classes. The city map legends are not standardized in the country, however, their class lists are more detailed than the classes used in the project. The reclassification reflects both five above mentioned land use classes and the COSMC land use classes distinguishing different ones: built-up, agricultural, forest, water, and other areas.

The final functional classes were residential, production, recreational, traffic and other areas. Each class is therefore formed by a higher number of city plan classes. The residential area is formed by mixed residential region, general residential and rural ones, and public areas, e.g. The reclassification means also including local roads belonging to roads of low level in the state road hierarchy into residential or other surrounding areas. The reclassification is

performed individually for each town according to its city plan classes.

The advantage of this approach was the fact that the basic classification was performed by urban specialists.

### B. Land Use Mapping

As the city plans comprise not only a real status, but also an urban plan (as it was mentioned above), the next step was to verify the present city plans and the real state of cities as they can and really significantly differ from the real state especially in newly urbanized areas. The second reason for the verification is also the city plans´ date of origin. This part of the processing was done by visual interpretation of the remote sensing data (aerial photographs) combined with a change registration/vectorization of the vector city plan and the result was a map of functional classes of the present state. The first map = the latest one (2009) was a result of the present city plan processing by implementing corrections found in discrepancies between the plan and aerial orthophotographs.

The previous time level of the land use map was derived from the present land use map copy by comparison with aerial photographs collected in between 1950 and 2000, and satellite image data (Thematic Mapper, MSS data) covering time span from 1970 to 2000. The satellite data were used for detection of land use changes between two time levels [6]. They were derived from a subtraction of original satellite image bands and normalized vegetation index in two different years (the 2008 band minus 2000 band, e.g.) and thresholding of the subtracted bands making the verification easier and quicker. Found changes were pixels with high positive or negative values. This approach yielded areas with different land cover, however, there was an additional task to determine and "translate" each land cover change into appropriate land use change. Each functional class comprises a wide range of the land cover classes in the aerial photographs spatial resolution; however, these detailed classes are not in prevailing part detectable on the Thematic Mapper data. The Thematic Mapper resolution does not allow determining urban functional classes – agriculture area spectral behavior can be similar to vegetated areas for some plants, etc. The areas with important changes (extreme positive and negative pixel values) were verified using the aerial photograph taking into account also their shape and texture. The oldest map showing the 1970 year was also in certain cases visually controlled using aerial orthophotomosaic created from aerial orthophotographs collected in 50-ies in the last century.

The principle of mapping based on the latest land use map as the first processed level and further steps heading back to the previous levels using always copy of the "younger" processed period as a base map for the "older" = previous time level proved to be the most effective. The current city plans´ and present land use state differences were not so numerous. There was another advantage of this approach; it allows ensuring the correct topology of each land use development map set, detected classes and their evolution.

All functional classes were controlled by the statistical table data available at the Czech Office for Surveying, Mapping and Cadastre for city administrative areas. The functional classes in individual years were used for further evaluation between the road transport density, town development and investments into road network in the form of new by-pass, highways, etc. The indicators showing the relation were the following: development of functional class areas, development of number of inhabitants, development of road transport density, and building of new decongesting roads.

## IV. ROAD TRAFFIC DATA

A large data base of the road network development has been created by the Road and Motorway Directorate. The data base comprises - among others - measurements of the road traffic intensity in many points of roads of various classes since 60-ies of the 20th century (1968, 1973, 1980, 1990, 1995, 2000, 2005, and 2010). The road traffic intensity is a number of vehicles per 24 hours, which passed through a determined point on a road in both directions. It is an average of several 24 hours´ data collection.

The measurements are available in map forms where each location is marked together with total amount of passed vehicles (including motorcycles), and tables where the amount is enumerated in a more detailed way distinguishing heavy-duty vehicles, cars and motorcycles.

## V. SOCIO-ECONOMIC DATA

A deep analysis of another large data volume which has been collected since the second half of the 20th century will be performed in the proposed project. The data comprise 10-year research of socio-economic data of environmental changes performed at the University of Economics in Prague, e.g. Each city is described by several hundreds of statistical data. The data were collected by many students of the university within their theses. The processing of the data is not presented in this paper and is a matter of the further research.

## VI. RESULTS

First twenty cities processed in the first year and a half of the project have brought very interesting results.

Kladno is one of processed towns situated 30 km north west from Prague. The town consists both of a core, and associated parts. The city was an industrial city in the communist period of the republic. The industrial production has been extremely declining since 1990 and most inhabitants are employed in Prague at present. Fig. 2 shows spatial changes of four functional classes between 1969 and 2009 mapped by the above mentioned method. The dashed line (Fig. 2a) determines the core area as an administrative city boundary at the end of 70-ies in the 20th century. The solid line delineates the administrative city boundary since 80-ies of the previous century which has not changed. The red color patches are residential areas in 1969. The green patches are residential areas built between 1969 and 2008 [3].

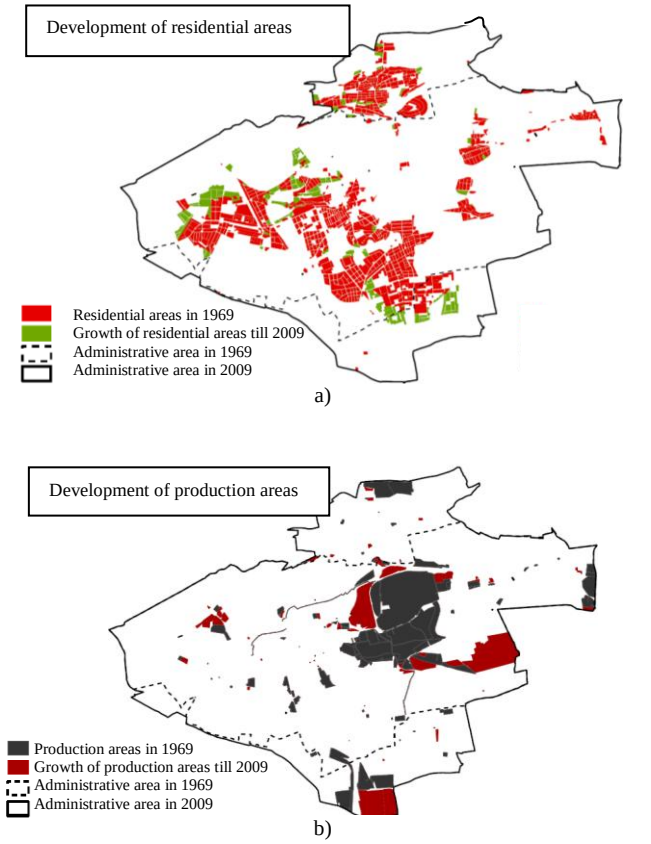


Figure 2a, b, c, d. Development of the Kladno functional classes for the 1969 – 2009 period

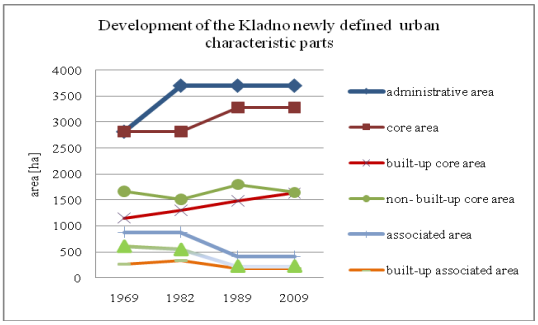


Figure 3. Example of spatial development of Kladno during last 40 years shown in administrative, core, associated, built-up and non-built-up areas

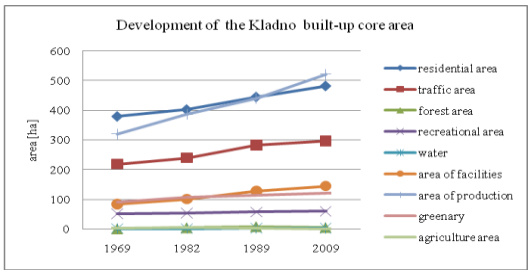


Figure 4. Example of spatial development of Kladno during last 40 years shown in land use classes

Development of production areas is shown in Fig. 2b, facility areas in Fig. 2c), and traffic areas in Fig. 2d.

Town development is further presented on two graphs – Fig. 3 and Fig. 4. Fig. 3 shows administrative, core and associated areas with their built-up and non-built-up area. Fig. 4 represents built-up core area. Looking at the statistical evaluation presented in Fig. 4, we can see that it was the area of production whose growth was the steepest in the core part. Comparing residential parts development, we can find that it covers larger areas with a steeper increase of size than those of traffic ones within the core region during last 20 years. However, there is a new highway passing the town in 5 km distance enabling the town to be used in prevailing part as a terminal location for the road traffic and not as a passing through town location in direction between Prague and north-west. The town has not yield larger areas for recreation, leisure time, sport, etc., during last 40 years (Fig. 4).

The administration area has not changed since 1982. The core area changed - unlike most towns - between 1982 and 1989. The residential area and area of production cover a similar part of the built-up area, however, the growth of the production area is steeper. Non built-up areas are in a prevailing part the forested ones. The associated areas are in most cases formed by an agricultural and forest land, however, their sizes decline after the 1989 political change. The spatial changes are described in the coincidence table

(Table I.). Each row shows the size of an individual class and its transformation between 1950 and 2008. Each column comprises original areas forming the present size of an individual class. Areas without changes are highlighted in diagonal cells of the table.Comparing of the last row (Sum 2008) and last column (Sum 1950) allows to find encrease and decrease of class areas.

The road traffic intensity was checked both on local and higher level class roads. Both road types express a growth, however, mutually uncomparable. The slope of the growth is lower after 1995 when a new pass-by highway was built (Fig. 5a). This phenomenon is presented as an impact of the highway construction out of the city on traffic intensity of the individual functional land use classes in Fig. 5b.

TABLE 1. THE COINCIDENCE TABLE SHOWS CHANGES BETWEEN 1950 AND 2008. RESIDENTIAL AREAS HAVE NOT CHANGED ON 207 HECTARES AND 25 % OF RESIDENTIAL AREAS HAS TRANSFORMED TO THE TRAFFIC, OTHER, PUBLIC, FACILITY, PRODUCTION, GREEN, AND AGRICULTURE AREAS (SEE THE RESIDENTIAL ROW). ON THE CONTRARY, THE PRESENT STATE OF THE RESIDENTIAL AREA IS NEWLY (AFTER 1950) FORMED BY TRAFFIC, OTHER, PUBLIC, GREEN, AGRICULTURE AREAS AND ENLARGED ON 130 % OF THE ORIGINAL SIZE (363 HA) (EXAMPLE OF THE CITY OF MĚLNÍK)

| | **Land Use Classes** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Land Use Classes** | ***Residential*** | ***Traffic*** | ***Forest*** | ***Other*** | ***Recreation*** | ***Public*** | ***Water*** | ***Facility*** | ***Production*** | ***Green*** | ***Agriculture*** | ***Sum 1950*** |
| residential | 207,47 | 5,56 | 0,00 | 13,06 | 0,00 | 11,79 | 0,00 | 8,32 | 16,94 | 9,98 | 4,01 | 277,14 |
| traffic | 6,24 | 34,55 | 0,95 | 0,34 | 0,16 | 9,40 | 0,00 | 0,21 | 1,83 | 2,86 | 8,16 | 64,97 |
| forest | 0,00 | 0,13 | 58,72 | 0,00 | 0,41 | 0,13 | 0,00 | 0,00 | 0,00 | 3,35 | 0,05 | 63,25 |
| other | 2,75 | 0,17 | 0,00 | 5,81 | 0,00 | 1,28 | 0,00 | 0,06 | 3,72 | 1,21 | 1,33 | 16,33 |
| recreation | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| public | 9,79 | 9,76 | 0,19 | 2,91 | 0,03 | 24,55 | 0,00 | 1,09 | 4,40 | 10,02 | 11,18 | 73,92 |
| water | 0,00 | 0,05 | 0,00 | 0,00 | 0,00 | 0,27 | 64,09 | 0,00 | 2,39 | 0,96 | 0,34 | 68,10 |
| facility | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| production | 0,68 | 1,34 | 0,00 | 3,61 | 0,00 | 2,87 | 1,50 | 0,00 | 66,55 | 3,54 | 0,00 | 80,09 |
| green | 14,09 | 5,47 | 0,00 | 6,94 | 1,63 | 10,40 | 0,00 | 3,27 | 8,66 | 123,28 | 14,66 | 188,88 |
| agriculture | 122,17 | 25,98 | 0,88 | 48,32 | 17,80 | 57,45 | 0,01 | 16,04 | 102,99 | 176,20 | 1082,75 | 1659,68 |
| sum 2008 | 363,19 | 83,01 | 60,74 | 80,99 | 20,03 | 118,14 | 65,60 | 28,99 | 207,48 | 331,40 | 1122,48 | |

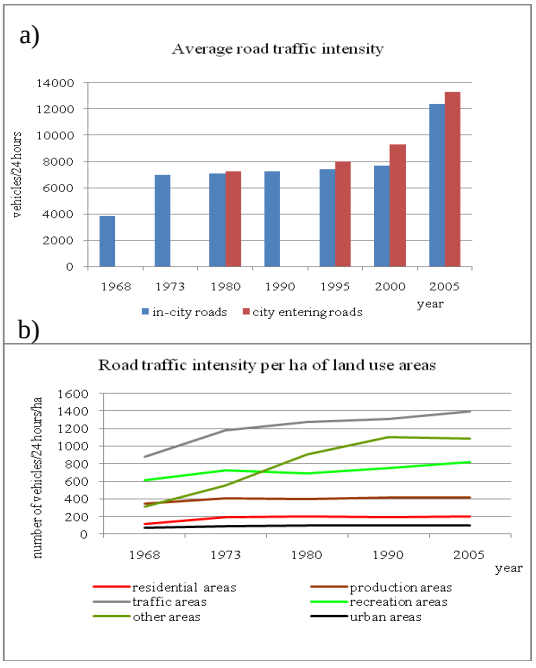


Figure 5. Sum of all measured segments on higher level roads used also for passing traffic and on local roads (a). Traffic intensity calculated as a ratio of all vehicles per 24 hours and size of functional areas (b)

Investments into highway and by-pass road constructions can be easily recognized from two graphs in Fig, 6. Ten towns with the highest number of vehicles per 24 hours entering and leavig each town were selected and compared to number of their inhabitants.

The important influence of by-pass roads can be found on Fig. 6. The city of Mělník has a very low number and growth of inhabitants in last 40 years if compared to Ostrava, as an example; however, numbers of measured vehicles leaving and coming to both cities are similar. Mělník does not have any by-pass road and is situated on the direction among Prague and other important Czech cities. Analyzing Kolín and Hradec Králové and/or Plzeň, their traffic intensity and number of inhabitants show analogue situations [3].

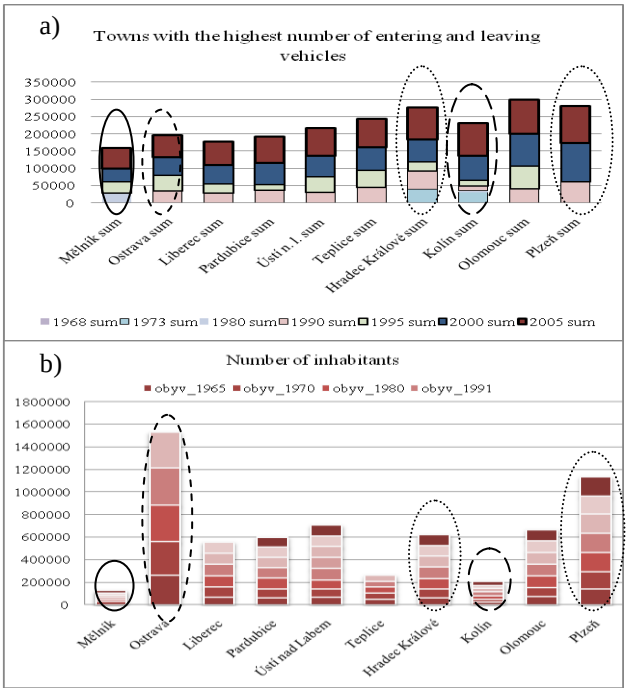


Figure 6 a, b. Comparing of the traffic intensity (a) since 1968 to 2005 and number of inhabitants (b) in similar periods (till 1991)

The traffic intensity was compared to land use classes in individual analyzed years.

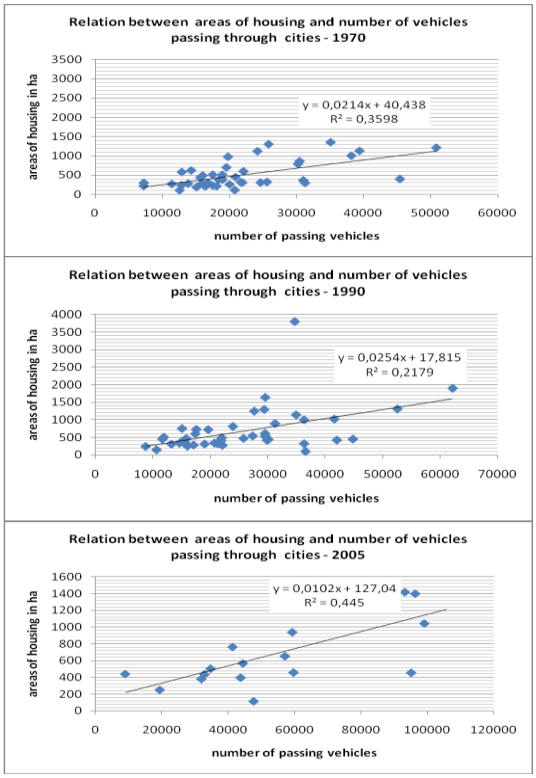


Figure 7. Graphs showing relation between number of vehicles passing through analyzed cities and their area of housing

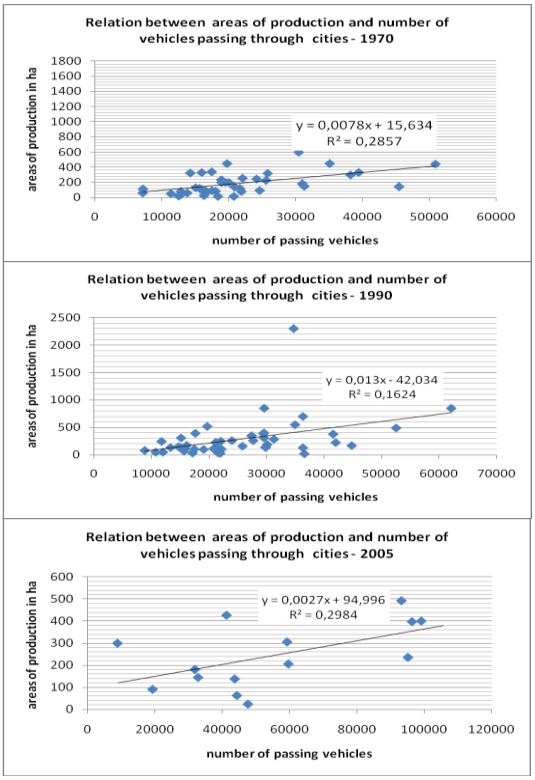


Figure 8. Graphs showing relation between number of vehicles passing through analyzed cities and their area of production

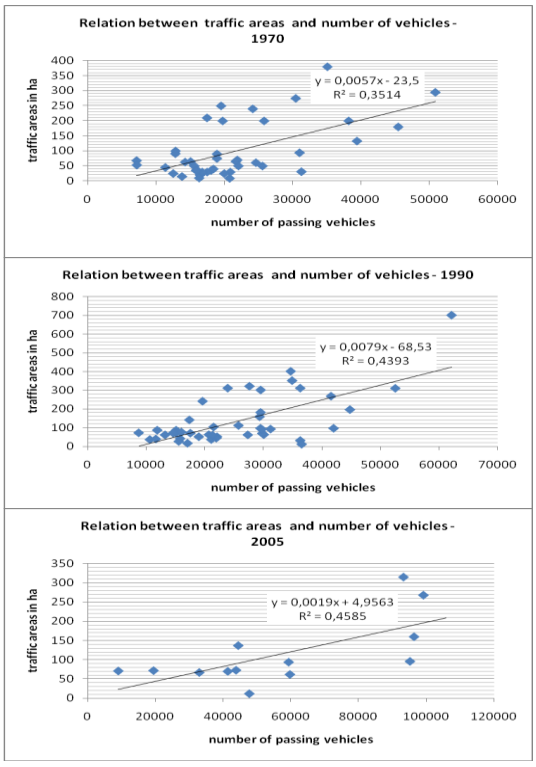


Figure 9. Graphs showing relation between number of vehicles passing through analyzed cities and their traffic area

TABLE II. CORRELATION COEFFICIENT OF RELATION BETWEEN ROAD INTENSITY OF PASSING VEHICLES AND AREAS OF VARIOUS LAND USE

| Correlation coefficient between road traffic intensity and areas | | | | | |
|---|---|---|---|---|---|
| | *urban areas* | *areas of housing* | *areas of production* | *areas of production and housing* | *traffic areas* |
| 1970 | 0,62 | 0,60 | 0,53 | 0,62 | 0,59 |
| 1980 | 0,34 | 0,35 | 0,24 | 0,33 | 0,57 |
| 1991 | 0,44 | 0,47 | 0,40 | 0,46 | 0,66 |
| 2005 | 0,70 | 0,67 | 0,54 | 0,67 | 0,68 |

The graphs on Figs. 7, 8 and 9 and Table II show that the best correlation between road traffic intensity and land use class occurs at traffic areas. These are areas of housing that have higher correlation coefficient on traffic intensity than areas of production. The best correlation for all land use areas has been found for 2005.

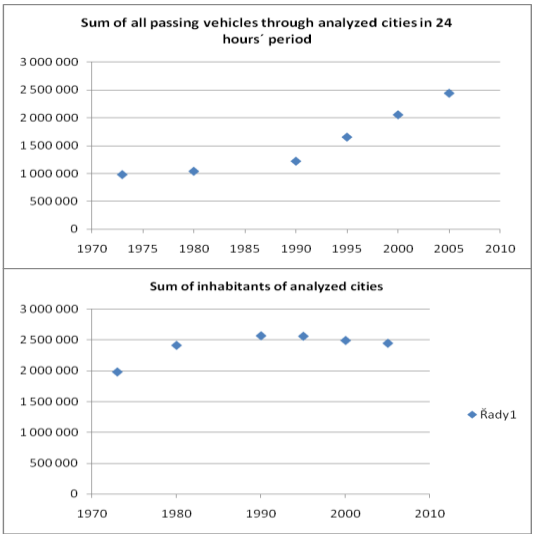


Figure 10. Development of number of passing vehicles through cities and their sum of inhabitants

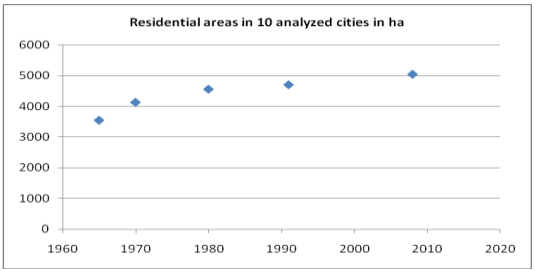


Figure 11. Development of residential areas in 10 analyzed cities

## VII. CONCLUSIONS

The project methodology is based on a multi-correlational processing using statistical (social, economical, geographical and natural) data of cities and spatial land use development and changes. There are more than six hundred economical, social and other statistical indicators whose mutual relation are prepared to be analyzed. The spatial land use change developments are visualized by the coincidence table (Table I.) and were used as the first group of indicators. Their correlation coefficients are in Table II.

Relations between town development and road traffic density showed interesting dependences. The traffic intensity changes cannot be generalized for a town as a unit. There are serious temporal changes within each town. These changes are caused by newly built commercial areas where this growth is incomparable to any other locations in the city, by new roads passing out of cities, e.g. The road traffic is also an important indicator of the economic inhabitant level – the traffic increase of personal and heavy-duty vehicles intensity on one side and decrease of motorcycle intensity and number of inhabitants on the other side since 70-ies is a proof of the higher economical power of city inhabitants which was found at all fifty analyzed cities. The fact is also documented on Fig. 10 by increasing sum of passing vehicles and decreasing number of inhabitants. The higher economical power proves also Fig. 11 accompanying Fig.10 and showing the growth of residential areas for the decline of inhabitants.

Results of any urban planning are always long lasting phenomena influencing the society. The spatial land use changes in 50 various cities will yield a rich source of data for the evaluation. The road traffic intensity is information on the air pollution; data on life expectancy are an issue concerning a social situation and health care, etc. The project results should offer a set of usable tools = indicators for urban planners and their further urban planning to achieve sustainable development of cities in the Czech Republic.

The paper presents a starting part of analysis performed for functional classes and road traffic intensity. Spatial changes and their relation to the traffic evolution have already brought a great deal of information which will be processed in a form of one of indicators.

The first part of the research was presented during the IARIA GEOProcessing 2011 [3].

The future research is focused on determining a list and sequence of indicators for the sustainable development of cities. The available data will be processed for selection of substantial indicators and their influence. There are still spatial ones, which have not been utilized as – distance to frontiers, distance to larger cities, etc. except for mainly socio-economical indicators that will be analyzed.

## ACKNOWLEDGMENT

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