Geographic Information System Models of 40-Year Spatial Development of Towns in the Czech Republic

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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 GIS 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 town developments and their relation to road traffic is presented on maps and graphs.**

Keywords-GIS, remote sensing data, city plan, number of inhabitants, urban model, land use, road traffic intensity, coincidence table, multicorrelational analysis

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.

Present state of the balance among consumption level of society and quality of life is a matter of scientific papers, research [2], [3], [4], 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.

The Department of Mapping and Cartography has been processing a 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 to ensure their sustainable development.

The project is a logical continuation of several projects performed by specialists from the Czech Technical University 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 classes housing and infrastructure areas, industrial and agricultural areas, areas of transport, areas of recreation including sport and green vegetation land, and areas of other functions,
2. Urban, agriculture, forest and water surface areas and other function areas from the Czech Office for Surveying, Mapping and Cadastre (COSMC) and Czech Statistical Office. The data are related to 1970, 1980, 1990, 2000, 2003, 2005 and 2008,
3. Basic components of the environment,
4. Basic components of the social and economical development.

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 size (from ten thousand to more than one million, by economic orientation (agricultural, industrial, university, touristic), by natural conditions (lowland surrounded by agricultural areas,

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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 transport intensity in the development.

land use city maps

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.

The spatial town development of first nine towns was derived from city plans designed by local administration, from aerial photographs collected between 1950 and 2008, and satellite image data (Thematic Mapper, MSS data) covering period between 1970 and 2000. The system of determination of individual time level of land use maps was based on map vector data representing municipal maps and the remote sensing data. Their content allowed to verify whether the mapped units are reality or the project author´s proposal. The supervised classification (maximum likelihood – used very often for land use/cover classification by many remote sensing specialists - [7], [8], e.g.) made the verification easier and quicker. The latest land use map was the first processed level and further step headed back to the previous levels. The land use maps were controlled by the statistical data of the Czech Statistical Office and Czech Office for Surveying, Mapping and Cadastre. Individual statuses for above mentioned years in urban land use functional classes – areas of housing, areas of facilities, industrialized areas, transport areas, recreational areas, green areas, and other areas.

II. 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 road classes since 60-ies (1968, 1973, 1980, 1990, 1995, 2000, 2005, and 2010) of the 20th century. The road traffic intensity is a number of vehicles. per 24 hours which passed through a determined point on a road in both directions. The measurements are collected in several thousands of selected locations in the Czech Republic and represent 24 hours´ period. It is an average of several 24 hours´ s 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.

III. 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 thesis. The processing of the data is not presented in this paper and is a matter of the further research.

IV. CZECH TOWNS 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. The third group of towns is similar to the second one; the only deference is in the further separation of one or more early joined villages. This development classification 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 1970. It was a year 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 called agglomerated ones. The parts which became independent villages later on, are called peripheral areas Vepřek in [8].

This spatial development is archived in Cadastre books in the form of table records showing concerned cadastre districts. The transfer of this information 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.

V. LAND USE CLASSES DETERMINATION

Land use class definitions were created from land use classes applied by urban engineers in city plans which were processed in several-year periods. Their classes in different cities are not standardized even though their dissimilarities in

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various cities are not important. However, their classification is too detailed for a general land use evaluation and was simplified to seven or nine land use classes in urbanized areas which were finally reclassified to five functional urban classes. These were the city plans which were the first information layer for urban land use maps processing.

The first step of preparing urban land use classes is a reclassification of detailed legend classes. 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. The reclassification means also including local roads belonging to roads of low level in the state roads 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, however, city plans comprise not only a real status, but also an urban plan. Therefore the next step was to verify the present city plans and the real state of towns as the plans comprise plans which may and really significantly differ from the real state especially in newly urbanized areas. 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.

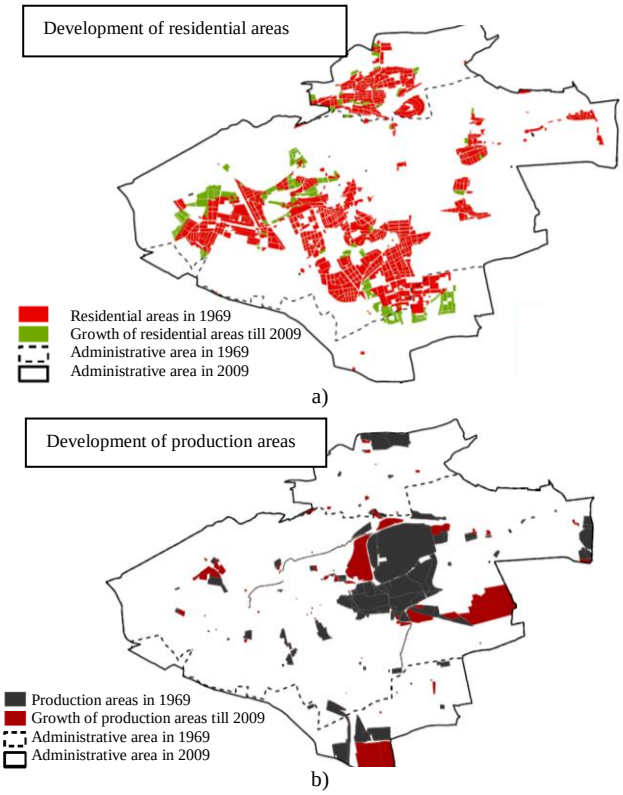
The forty years development was divided into determination of previous phase maps of functional classes in 2000, 1990, 1980 and 1970. The process started in the latest period and ended in 1970. These maps were processed using remote sensing data. Two types of remote sensing data were used for the change detection allowing mapping of the given year. The latest map (2008) was a result of the present city plan processing by implementing corrections found in discrepancies between the plan and aerial orthophotographs. Satellite data - Thematic Mapper (TM) data - were utilized for determination of land cover changes. They were derived from a subtraction of original satellite image bands and normalized vegetation index in two different years (2008 band minus 2000 band). 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" a land cover change into a 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 visually controlled using aerial orthophotomosaic created from aerial orthophotographs collected in 50-ies in the last century.

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 road transport density, town development and investments into road network in the form of new by-pass, highways, etc. Following indicators showing the relation were: development of functional class areas, development of number of inhabitants, development of road transport density, and building of new decongesting roads.

VI. RESULTS

First nine cities processed in the first year 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. Figure 1 shows spatial changes of four functional classes between 1969 and 2009 mapped by the above mentioned method. The dashed line (Figure 1 a) determines the core area as an administrative city boundary at the end of the 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.



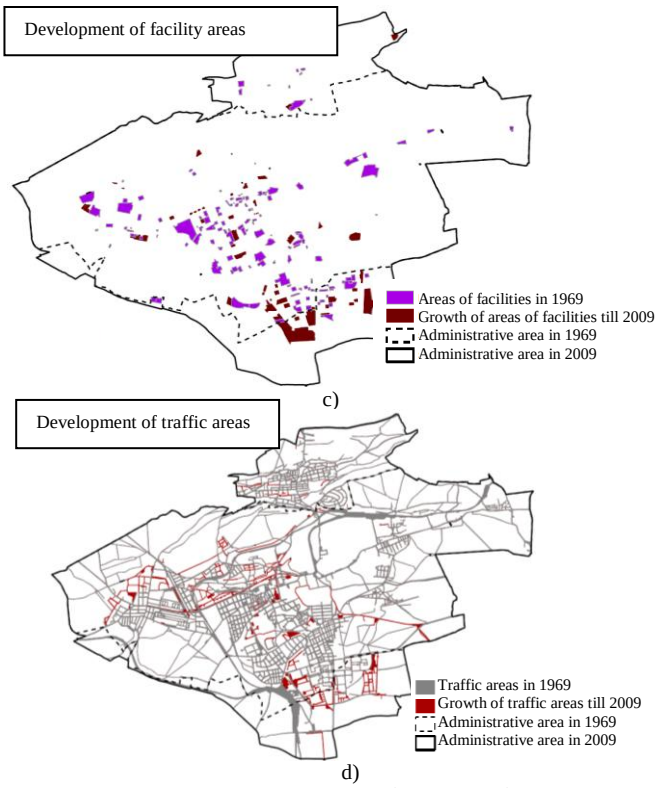


Figure 1a, b, c, d. Development of the Kladno functional classes for the 1969 – 2009 period

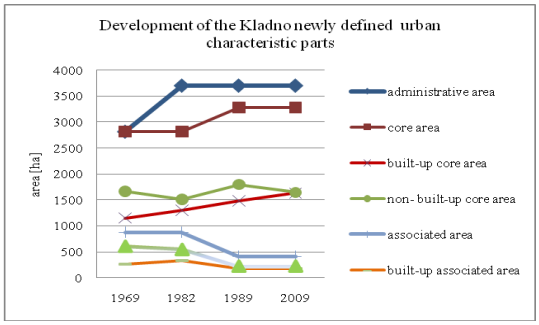


Figure 2. Example of spatial development of Kladno during last 40 years shown in administrative, core, associated, built-up and non-built-up areas

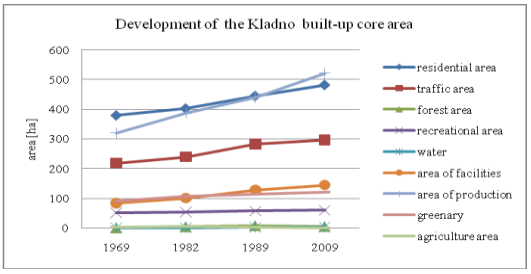


Figure 3. Example of spatial development of Kladno during last 40 years shown in land use classes

Development of production areas is shown on Figure 1b, facility areas on Figure 1c), and traffic areas on Figure 1d.

Town development is further presented on two graphs – Figure 2 and Figure 3. Figure 2 shows administrative, core and associated areas with their built-up and non-built-up area. Figure 3 represents built-up core area. Looking at the statistical evaluation presented in Figure 3, 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. The town has not yield larger areas for recreation, leisure time, sport, etc., during last 40 years (Figure 3).

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 declineafter the 1989 political change . The spatial changes are described in the coincidence table (Table 1). 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 (Figure 4a). 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 on Figure 4b.

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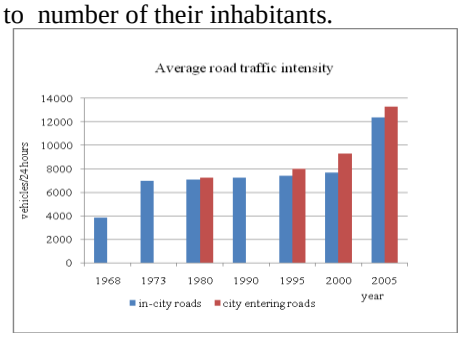
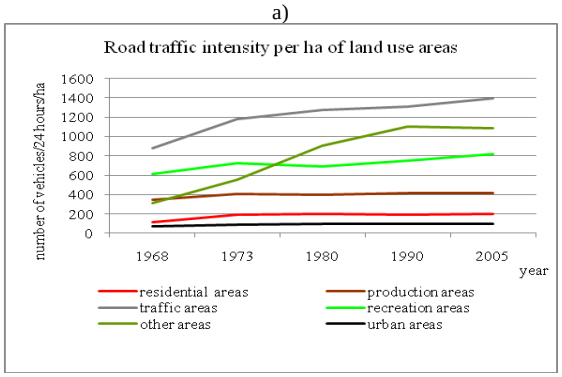
TABLE 1. THE COINCIDENCE TABLE SHOWS CHANGES BETWEEN 1950 AND 2008. RESIDENTIAL AREAS HAVE NOT CHANGED ON 207 HECTARES AND 25 % OF RESIDENTIAL AREAS HAS TRANSFORMED TO THE TRAFFIC, OTHER, PUBLIC, FACILITY, PRODUCTION, GREEN, AND AGRICULTURE AREAS (SEE THE RESIDENTIAL ROW). ON THE CONTRARY, THE PRESENT STATE ÓF 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	

Investments into highway and by-pass road constructions can be easily recognized from two graphs in Figure 5. 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.



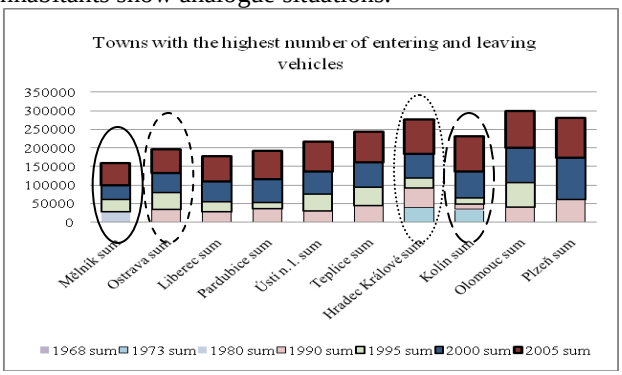
a)



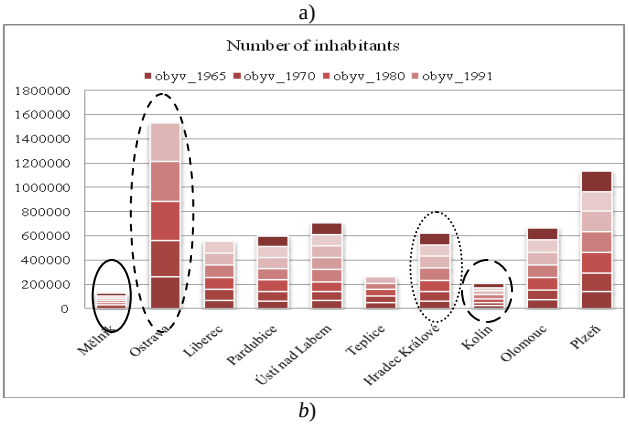
b)

Figure 4. 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)

The important influence of by-pass roads can be found on Figure 5. The city of Mělník has a very low number and growth of inhabitants in last 40 years if compared to Ostrava, e.g.; 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, their traffic intensity and number of inhabitants show analogue situations.



a)



b)

Figure 5 a, b. Comparing of the traffic intensity (a) since 1968 to 2005 and number of inhabitants (b) in similar periods (till 1991)

VII. CONCLUSIONS

The project methodology is based on a multicorrelational 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 development visualization can be usefully presented by coincidence table.

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 the city inhabitants which was found at all fifty analyzed cities.

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 very small 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 future research is focused on determining a list and sequence of indicators for the sustainable development of cities.

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