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Comparison of air, road, time and cost distances in Hungary

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ABSTRACT

The aim of this study is to discuss the differences between geographical, road, time and cost distances by the help of the Hungarian railway network and road network data. The first section deals with the general characteristics of distances and spaces and the validity of metrical axioms in time and cost space. Time and cost space are more complex than geographical space, because there is just one and only air kilometers and the kilometer distance between points of network can be determined more or less exactly. Time distances and cost distances fall into an interval and at best only about shortest or typical distances, shortest or typical lengths of time and least or typical costs can be spoken. The second and third sections compare local and global the geographical space and various road, time and cost spaces.

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Introduction

Differences between various spaces can be measured with various global and local indices. Global indices show the size of differences between two spaces as a whole, whereas local indices describe the distortion of a point or a smaller area compared to a reference space. The reference space of comparison is often but not always the geographical space. Local indices are able to detect points and areas where some barrier of connection may exist and where improving the network may have the biggest effect on the change of accessibility. Graph theory also can be effectively used in measuring the properties of the networks.

The aim of this paper is to present some Hungarian examples for the construction and visual representation of non-Euclidean geographical spaces. The methodological framework of analysis can be briefly summarized in the followings. There are a set of distance relations between various locations, obtained for example from the transportation system of a geographic space. The data should be organized in a matrix with all sets of origins and destinations. Multidimensional scaling uses the distance matrix as input and then generates another matrix, containing the coordinates of points of the investigated space. Diagnostic tools of multidimensional scaling help to determine whether a meaningful spatial structure exists. (Ahmed – Miller, 2007)

Bidimensional regression can compare the result of multidimensional scaling (MDS) with the geographical space. Bidimensional regression is a method to compare two or more two-dimensional surfaces. It is an extension of linear regression where each variable is a pair of values representing a location in a two-dimensional space. Bidimensional regression numerically compares the similarity between two-dimensional surfaces through an index called bidimensional correlation. The three different spaces and distance matrices (reference or source map, image map and predicted map) can be compared pairwise, therefore three different distance/(dis)similarity measures can be created, not just one, as in the case of unidimensional regression.

The visual representation of various spatial relations and map transformations were carefully examined in the path-breaking works of Waldo Tobler (Tobler, 1961; Tobler, 1963). Multidimensional scaling is a well-known statistical tool used in many fields of research. Regarding the use of multidimensional scaling in spatial analysis, one has to mention among the first use of method Marchand (1973) paper, Gatrell's monograph (Distance and Space, 1983), articles by Spiekermann and Wegener. Bidimensional regression was originally developed in 1977 by Waldo Tobler but was not widely known until the technique was

published in 1994. Compared to the multidimensional scaling, bidimensional regression is not an as well known method. It is applied to analyze and measure the relative distortion of historic maps (for example Lloyd and Lilley, 2009; Symington et al., 2002), to compare cognitive maps (Friedman–Kohler, 2003) and to compare spaces generated by multidimensional scaling (Ahmed–Miller, 2007). About the methodological framework of the analysis Ahmed–Miller, Axhausen–Hurni and Friedman–Kohler also give an excellent overview.

1. Distances and spaces in general

The concept of distance and space is the principal category in geography and should be treated in a more adequate manner in other fields of study, such as in most of the parts of regional economics. It is well known for the spatial researchers that aspatial techniques cannot capture the relationships inherent in geographic phenomena. Spatial investigations often require either special research methods or spatial adaptation of aspatial techniques.

It is both impossible and unnecessary to give a general concept of space. At the beginning of the majority of works concerning the spatial problems a philosophical or scientific definition of space or at least a review about the various space concepts is given. Among the general philosophical space concepts the absolute, relational and Kantian interpretations can be distinguished. According to absolute space concept, space is an object beside other objects. Relational space concept treats the space as a relation between the objects which has no existence apart from the existence of those objects. Kant described the space as an a priori notion that allows us to comprehend sense experience. The term space is used in pure mathematics also, where a space is a set, with some particular properties and usually some additional structure. Space definitions of mathematics have nothing in common with the ordinary everyday use of the word but of course from a mathematical point of view it is entirely adequate.

These various concepts of space have reason for the existence in different contexts and no one can be treated as an absolute or exclusive definition. Euclidean geometry, architecture and everyday experience support the absolute space view. Results of physics speak in favor of relational space. From psychological point of view Kantian space view is acceptable. It makes only trouble when someone lays claim to exclusiveness of one particular definition of space. It is a strange situation when for example the absolute space view of Euclidean geometry is

challenged and criticized from the point of view of relativity theory of physics. The opposite claim would sound more absurd, namely to criticize the relativity theory because of absolute space view of Euclidean geometry. Relativity theory is neither useful for the investigation of architectural space. Products of architecture are spaces itself and for the architecture space is treated as an absolute three dimensional immaterial (in the everyday use of the word) expansion.

The shortest ways between the points of a network generates the space of transport network, the shortest (or average) time which is needed of reaching from one point to another creates the time spaces, the lowest (or average) cost which is needed to reaching from one point to another forms the cost spaces. The order of enumeration of different spaces corresponds to the order of their calculability. Firstly, the space of transport network has to be calculated then knowing the physical characteristics of the network, time spaces (for example time space of public transport, individual transport, carriage) can be determined, and at last the various cost spaces can be identified. The shortest route between two points can be different in physical sense in various spaces, for example, using the motorway, time can be shorter but distance in kilometers can be longer and the monetary cost can be higher than other possible routes. In railway traffic, high speed trains operated typically only between pairs of large cities. The different types of trains (stop trains, fast trains, Intercity or high speed trains) can be joined when someone wants to travel from a small location to a farther bigger centre or back (see examples for this in Kotosz, 2007). Beside the speed differences, the monetary costs can be different also and the schedule effect has to be taken into account too.

Geographical space is continuous, each point of a topographic map can be interpreted as an element of space. However, the time and cost spaces contains nodes and lines. The network structure means that exact distances are interpretable only between the nodes and not for a surface.

The geographical space has metrical characteristics, that is, prevail these axioms:

1. The distance between two points is zero if and only if the two points are identical (the separation axiom).
2. The distance between two points is positive if the two points are different.
3. The distance from point A to point B is identical with the distance from point B to point A (symmetry axiom).

4. The distance from point A to point B cannot be larger than the sum of the distance from point A to point C and the distance from point B to point C (axiom of triangle inequality).

The first two axioms are valid in time spaces also. Points which are different in geographical space, will be different in time spaces also, because time is necessary for surmounting distance (apart from the special case of telecommunication). The problems arising in connection with the first two axioms in time spaces are to give an operational method that permits us to identify the points themselves. Allocating the points of a network can be a vivid question in practical research. The validity of the first two axioms in the cost spaces is a more complicated question. The cost distance between two points can be zero if the two points are different because of pricing policy of entrepreneurs.

Symmetry axiom is valid neither in time spaces nor in cost spaces. In the case of individual transport in cities, the one way streets, the direction dependency of traffic and the vertical differences of roads invalidate the axiom. The axiom is not valid even in intercity traffic, but the differences between the directions are smaller than in intracity transport. Flying time can be also different because of the dominant direction of wind (for example between Europe and North America). As regards the cost spaces we do not go into details, but there are several examples for direction dependence of costs.

The triangle inequality axiom is valid in individual transport but it is invalid in public transport due to the dead time of change transport means or due to the different speed of different lines. The triangles of geographical space are not identical with the triangles of time spaces and cost spaces: the former one is based on air distances, the latter one based on time distances and cost distances, which can be distorted thanks to uneven density of network systems, the route sinuosity and different maximal or average speed on different elements of network, and because of change between network subsystems.

3. The study area and data

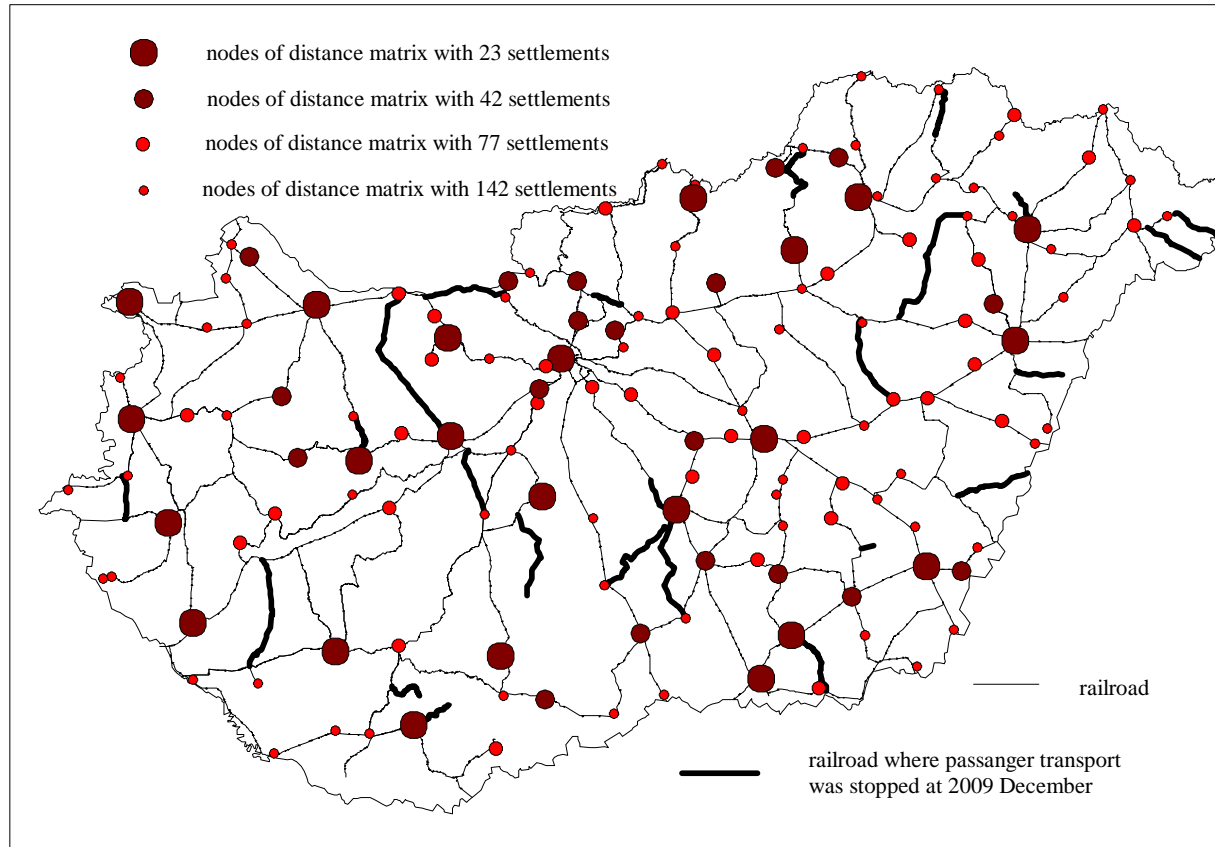
The paper analyses the spaces of Hungarian railway network and public road network. The shortest road distance in kilometers, time distance in minutes for both networks and for the railroad the cost distance in Hungarian Forint were completed. The source of railroad data is the timetable of Hungarian Railway. The reference matrix includes the air distance. The largest distance matrix was calculated for 142 nodes: the biggest cities, railway junction

settlements (sometimes these are smaller cities or villages) and the endpoints of the network. The other three matrices consist of 23 points (the cities with county rights), 42 points (the cities with county rights and other medium size cities) and 77 points (the cities above 15 thousand inhabitants).

The emphasis is on the railroad network. For the sake of comparability the public road network consists of the same points as the railroad network. The map of Hungarian railway network can be seen on the Figure 1. According to the new time schedule in 2009 December, the passenger transport is stopped on 29 railway lines (altogether 868 kilometers). The calculation was conducted for both networks, therefore those points were chosen for the analysis, which are available with the reduced network also.

Previous works on the subject (for railway Kovács, 1973; for railway and public road Szalkai 2001; Szalkai 2004; for public road Fleischer, 1992) concerns a larger railway network and used the detour index and isodistance maps with Budapest centre for the description of relative accessibility of the nodes of the network.

Figure 1 The Hungarian railway network (with nodes of various distance matrices)



4. Results of multidimensional scaling

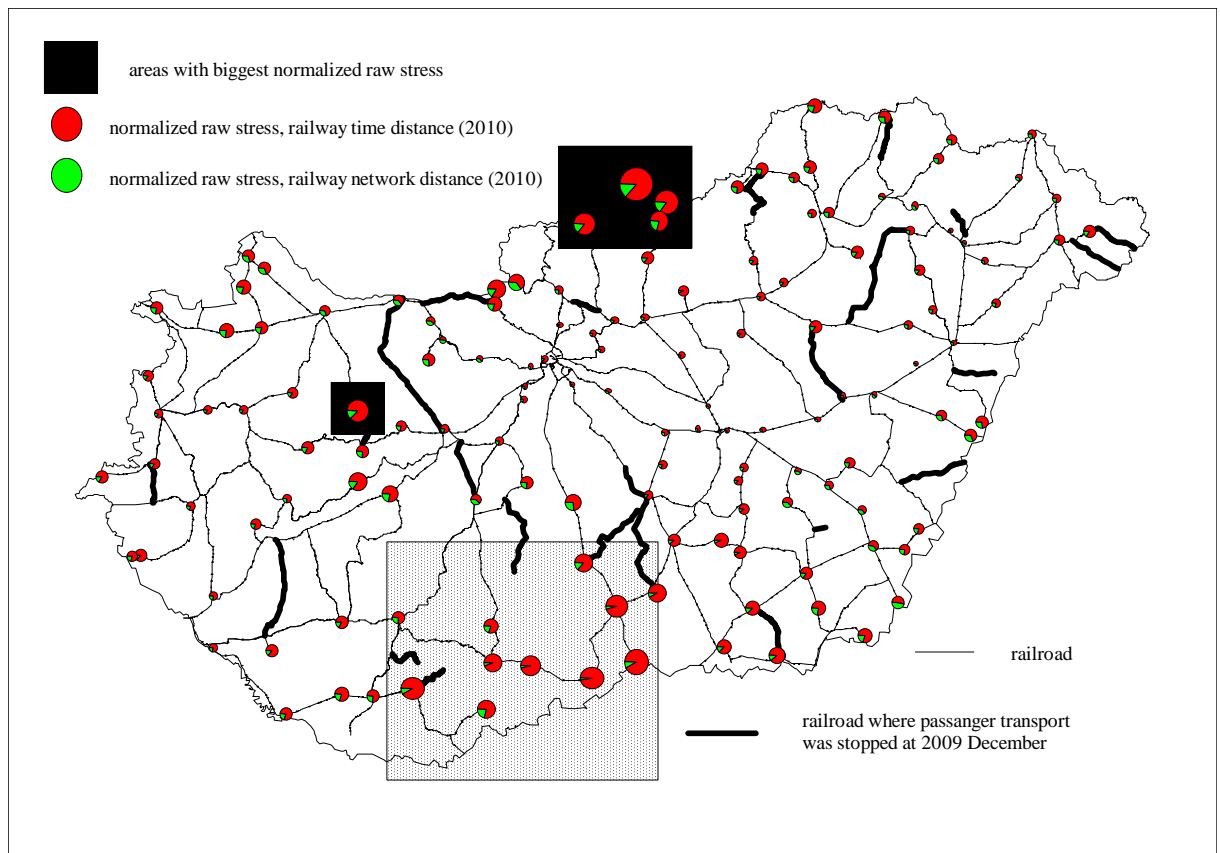
The 28 distance matrices were analyzed by PROXSCAL technique of multidimensional scaling. The normalized raw stress of 28 distance matrices can be seen on Table 1. The normalized raw stresses are between 0,8% and 4,5%, which means that the general configuration of distance matrices can reproduced well or on an acceptable level in two-dimensional Euclidean spaces. In the case of time distances the stress always higher, because of the different speed of various parts of the network. The biggest network has higher stress in the case of railway time distance. The reason for this that the smaller locations are not accessible with high-speed trains therefore the difference between average speeds is higher. The size of the network has also impact on the results, but in a different manner for time distance of railway and time distance of public road. This can be explained by the dead time of changing trains when someone wants to travel to a smaller location.

Table 1 Normalized raw stress of distance matrices (%)

	23 nodes	42 nodes	77 nodes	142 nodes
Network distance, railway, 2009	0,88	0,85	0,88	0,91
Network distance, railway, 2010	0,97	0,97	0,98	1,01
Time distance, railway, 2009	1,90	2,44	2,18	3,11
Time distance, railway, 2010	2,22	2,70	2,38	4,19
Cost distance, railway, 2009	1,83	1,77	2,07	2,56
Network distance, public road	0,78	1,22	1,15	1,28
Time distance, public road	3,20	4,54	1,39	1,54

It is interesting to analyze the decomposition of stress also. The contribution to stress by points can be seen on Figure 2 for the network distance matrix (2010) and time distance matrix (2010). Those areas can be identified very well, where the structure of network highly uneven.

Figure 2 Decomposition of normalized raw stress (network distance matrix and time distance matrix, 2010)



5. Results of bidimensional regression

In this preliminary stage of this research only some general results will be presented in the form of various figures. The calculations and graphical representation was conducted by program Darcy 2.0. (Downloadable from the homepage <http://www.spatial-modelling.info/Darcy-2-module-de-comparaison>) A description about the program and the method can be read in Cauvin's paper. (Cauvin, 2005) Figure 3 serves as a reference map, with the county borders of Hungary, with the cities with county right and with the adjusted coordinates of multidimensional scaling of railway network distance matrix.

Figure 3 County borders of Hungary and cities with county right (geographical location: blue dot, MDS location: orange dot)

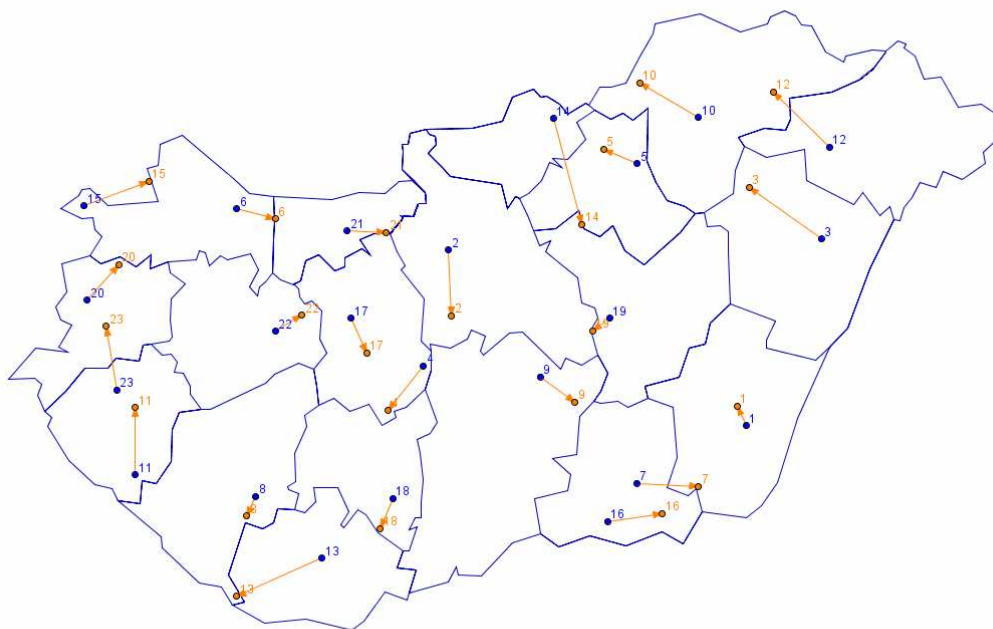


Figure 4 Railway network distance space, 2010

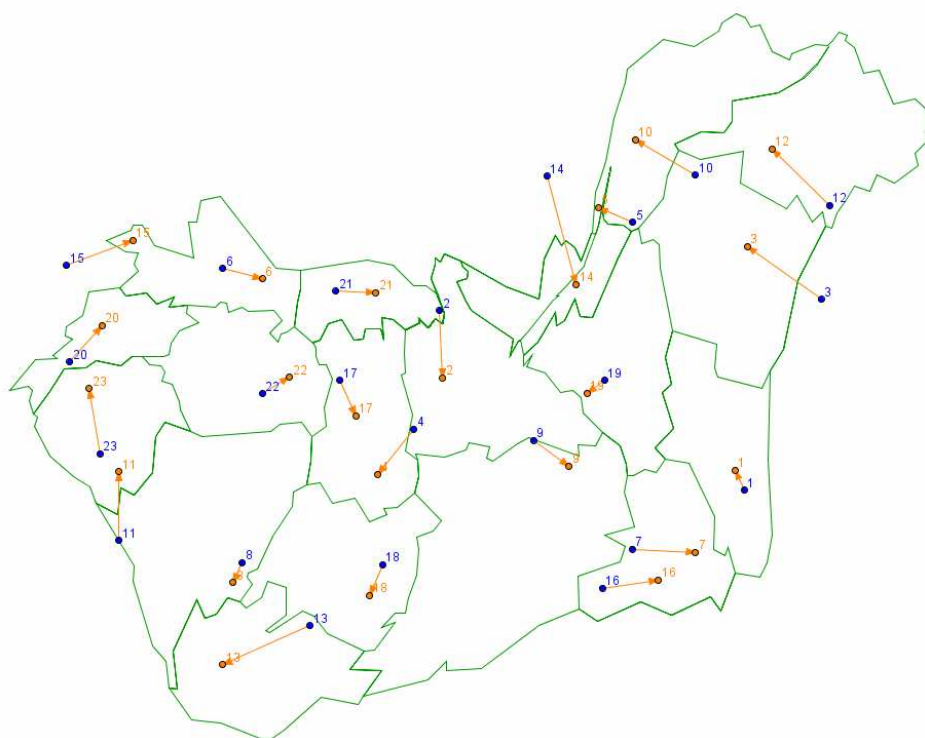


Figure 5 Railway time distance space, 2010

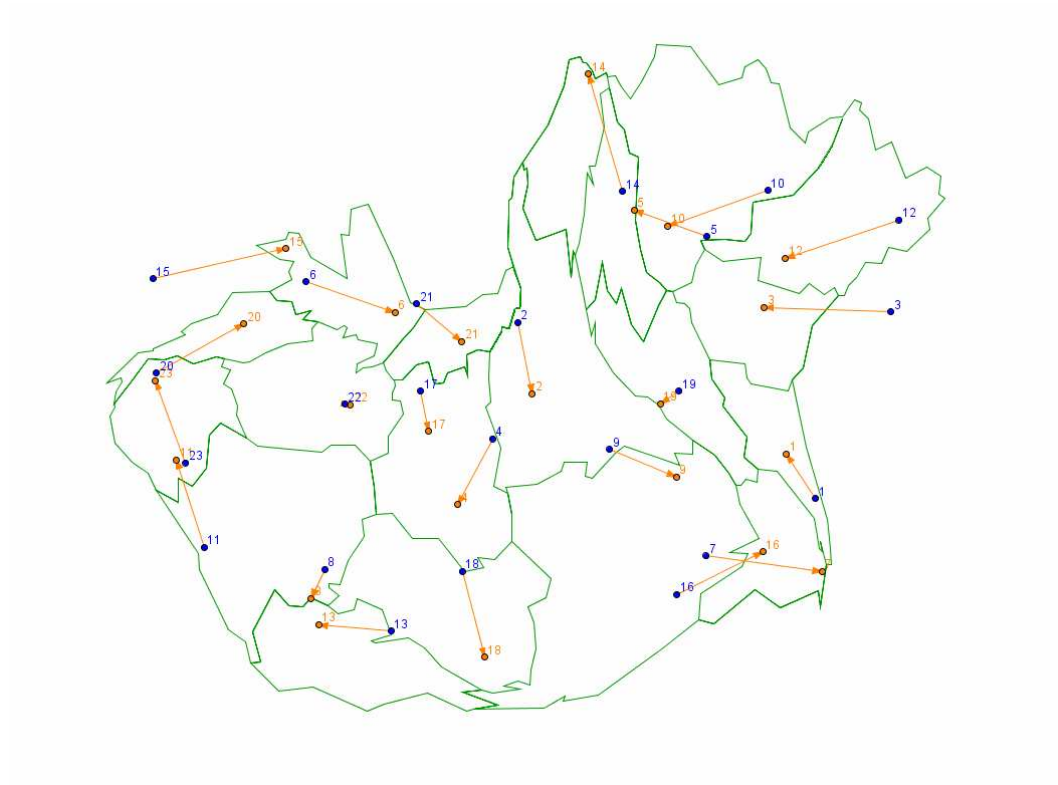


Figure 6 Railway time distance space with displacement vectors, 2010

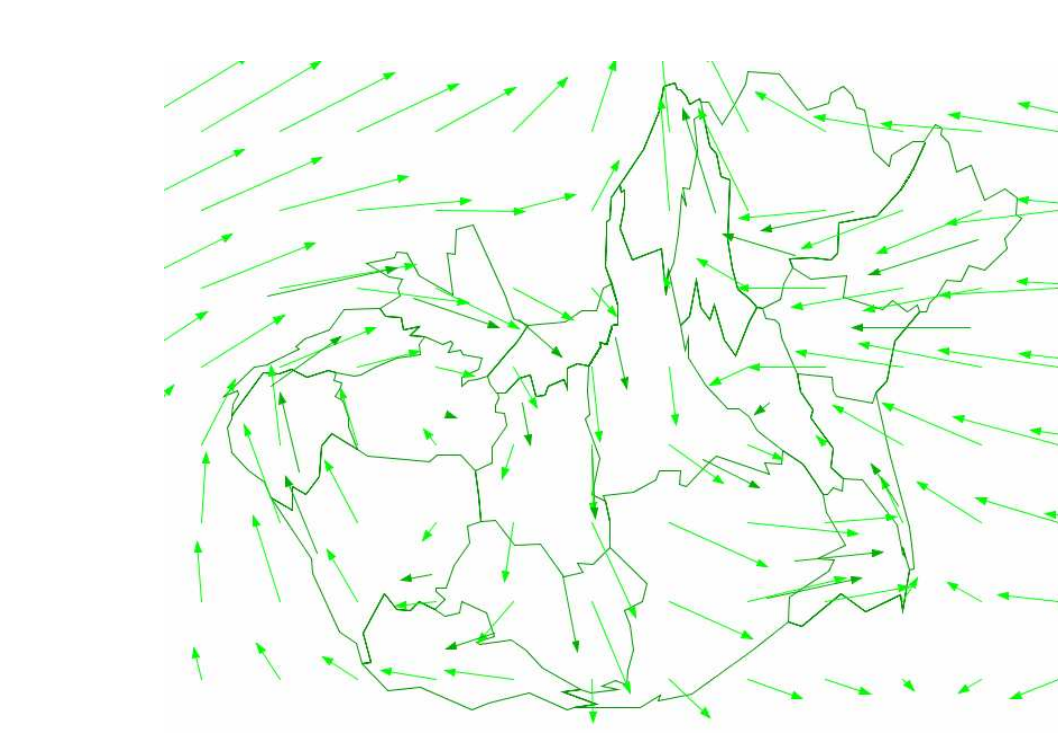


Figure 6 Railway cost distance space, 2010

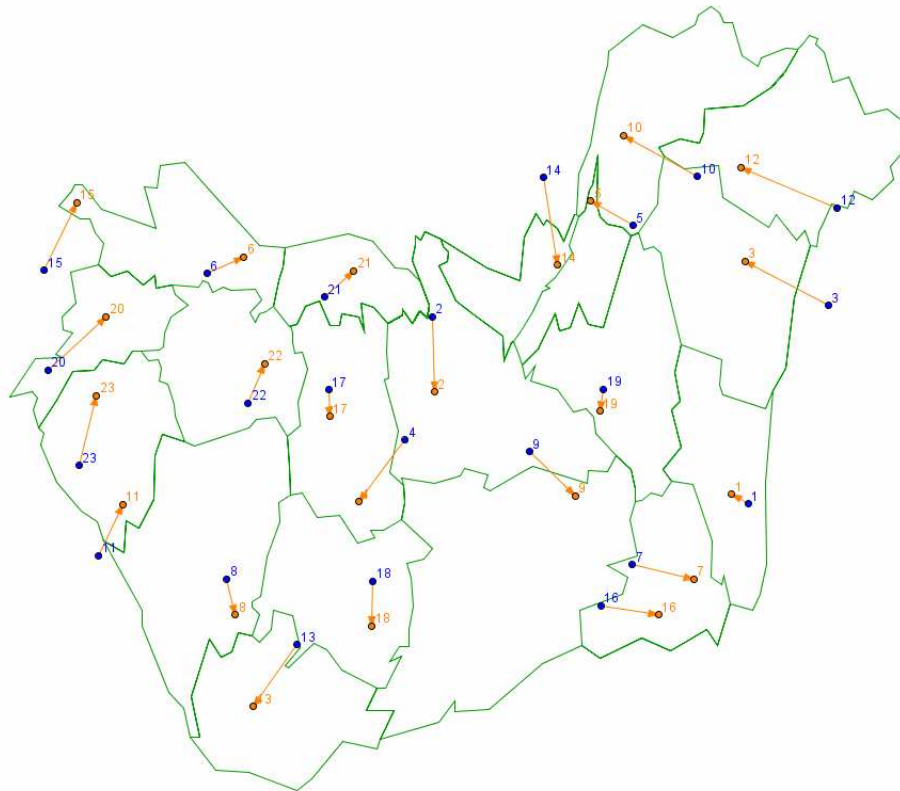


Figure 7 Public road network distance space, 2009

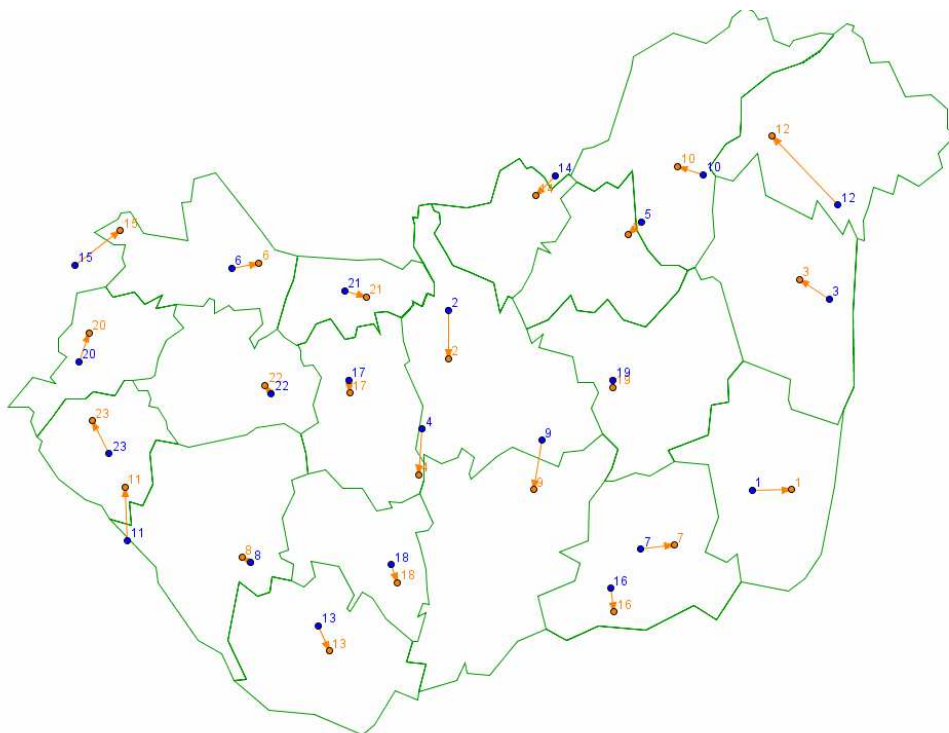
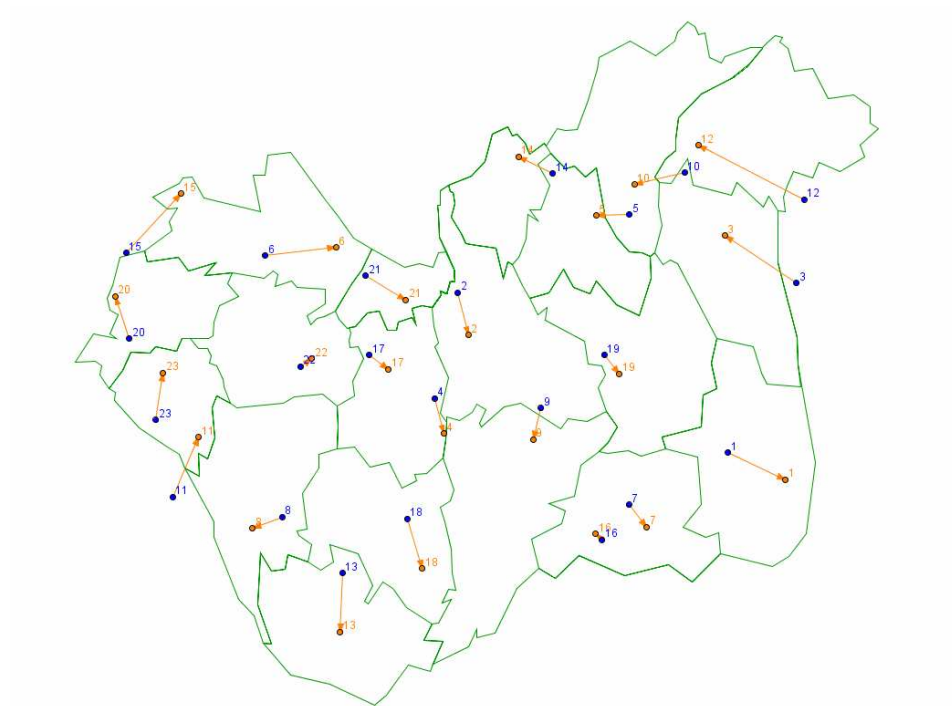


Figure 8 Public road time distance space, 2009



There are two common characteristics of all maps: firstly, the widening of east-west distances in southern part of the country. Danube has the biggest barrier effect in Hungary, south from Budapest there are just one railroad bridge and three public road bridges over the Danube, solving the east-west traffic. Secondly, space around Budapest is narrowed, because of radial character of network, with Budapest in the centre. These two characteristics can be seen on Figure 6, where the displacement vectors of transformed geographic space are depicted.

Summary

Non-Euclidean spaces cannot be represented in two dimensions without stress and residuals. However, the depicted transformed maps show a more accurate picture about the various distance matrices than the geographical maps, based on air distances. Important limitation of the maps is that they suggest (similar to topographic maps) a continuous space, but in reality the depicted spaces consists of nodes and lines.

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