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Comparison of Air, Road, Time and Cost Distances in Hungary

The aim of this study is to discuss the differences between geographical, road, time and cost distances with 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 only one measurement of air kilometer and the kilometer distance between points of network can be determined more or less precisely. However, time distances and cost distances fall into an interval and at best only shortest or typical distances, shortest or typical lengths of time and the cheapest or typical costs can exist. The second and third sections compare locally and globally the geographical space and various road, time and cost spaces.

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 barriers of connection may exist and where improving the network may have the biggest effect on the change of accessibility. Graph theory can also 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 following. There is a set of distance relations between various locations, obtained for example from the transportation system of a geographical space. The data should be

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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 groundbreaking 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 to use this method Marchand (1973) paper, Gatrell's monograph (Distance and Space, 1983) and 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 as well known. 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.

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 areas of regional economics. It is well known to 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 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 the absolute space concept, space is an object beside other objects. The 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 a priori notion that allows us to comprehend sense experience. The term space is also used in pure mathematics, where a *space* is a set, with some particular properties and usually with 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 not one of the concepts 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 favour of relational space. From a psychological point of view, Kantian space view is acceptable. It only causes 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 the relativity theory of physics. The opposite claim would sound more absurd, namely to criticize the relativity theory because of the absolute space view of Euclidean geometry. The relativity theory is not useful for the investigation of architectural space either. Products of architecture are spaces themselves and architectural 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 generate the space of transport network, the shortest (or average) time which is needed to reach from one point to another creates the time spaces, the lowest (or average) cost which is needed to reach 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 knowledge of the physical characteristics of the network, time spaces (for example time space of public transport, individual transport, carriage) can be determined, and last the various cost spaces can be identified. The shortest route between two points can be different in the physical sense in various spaces, for example, using the motorway, time can be shorter but the distance in kilometers can be longer and the monetary cost can be higher than other possible routes. In railway traffic, high speed trains operate typically only between pairs of large cities. The different types of trains (stopping 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 also be different 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 contain 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 to 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 also valid in time spaces. The first axiom is not valid in cost spaces; the third and fourth axioms are valid neither in time spaces nor in cost spaces. The reasons for this and several examples are discussed elsewhere, see for example Dusek – Szalkai (2006).

SOME MORE WORDS ABOUT THE USE OF MULTIDIMENSIONAL SCALING

It is an interesting fact that originally the multidimensional scaling was a result of the mathematization of psychology in the nineteen thirties and forties. In the journal Psychometrika, the most ground-breaking papers on the subject were published (Young, 1987). Besides in psychology the method is widely used in marketing, sociology, political science, anthropology, and linguistics. Stefflre's following interpretation of the essence of the method can be treated as typical: "Multidimensional scaling refers here to the analysis of judged similarity data (individual or aggregate) by techniques that attempt to represent these data by a spatial configuration" (Stefflre, 1972, 211.). Thus, non-spatial applications of the method were the first, but as an illustrative example, geographical distance matrices are often used as an input matrix and spatial configuration of the geographic objects (mainly settlements) is the output of the method. For example, János Podani (1997) uses ten European metropolises, Gatrell (1983) British cities, Greenacre and Underhill (1982) Southern African airports in their examples.

Imre Lengyel also mentions the possible spatial use of the method. In his analysis there are spatial objects (Hungarian cities), but the distance matrix were calculated not by geographical characteristics but socio-economical differences (Lengyel, 1996; Lengyel, 1999). For non-spatial applications, the creation of the input distance matrix is an interesting and methodologically important question. For example, in psychology attitudes, opinions and emotions measured by Likert-scales some distance is created, but there is not an obvious methodology to transforming these pairwise distances to a whole distance matrix.

The nonmetric case is also more frequent in non-spatial applications, when only the ranks of the distances are known between the various objects.

There are numerous measures for the goodness-of-fit (or sometimes named badness-of-fit) of the reproduction of the input distance matrix. The most obvious choice for a goodness-of-fit statistic is one based on the differences between the actual distances and their predicted values. Kruskal proposed the following formula, called Stress-1 in the literature:

$$Stress-1 = \sqrt{\frac{\sum\left[f(p_{ij})-d_{ij}(x)\right]^2}{\sum d_{ij}^2(x)}}$$

Where f(pij) means the distances calculated by the multidimensional scaling, dij(x) means the original distances in a standardized form. The average of the square of the standardized distances is 1. This is the most common stress measure. Other measures of stress are different only mainly in the way of standardization. Kruskal (1964) proposed the following interpretation of this measure: above 0.2 the solution is poor, between 0.025 and 0.05 it is excellent, and when it is under 0.025, it is perfect (Table 1). Another proposal came from Guttmann, who drew the line of acceptable-unacceptable solution at 0.15 (Borg – Groenen, 1997, 37.).

Table 1: The interpretation of Stress-1 according to Kruskal (1964)

Stress-1	Goodness-of-fit
0.2<Stress-1	poor
0.1<Stress-1≤0.2	fair
0.05<Stress-1≤0.1	good
0.025<Stress-1≤0.05	excellent
0≤Stress-1≤0.025	perfect

Source: Kruskal (1964).

However, these proposals are deceptive. The least problem is that these values cannot be interpreted as strict borderlines, and context is always important. The biggest problem is that the goodness-of-fit can be interpreted only in a mathematical sense as a good-wrong scale, where bigger values mean a worse solution. Stress-1 above 0.2 is wrong only from a mathematical point of view, but otherwise good, because this perfectly mirrors the complexity of actual distance relations. Borg and Groenen, surveying previous methodological studies and simulations, summarized the various factors, which have an influence on the stress measures. These can be seen in Table 2.

Table 2: Factors influencing the stress measures

Factor	Effect on stress
Number of dimensions (m)	The higher m, the lower stress
Number of points (n, observations)	The higher n, the higher stress in general
The error in the data	More error means higher stress
The number of missing data	More missing data leads to lower stress, in general
The MDS model	Interval MDS generally leads to higher stress than ordinal MDS

Source: Borg – Groenen (1997).

For the sake of illustrating Stress-1 measure, its value for various MDS solutions of distance matrices among the six biggest Hungarian cities can be seen in Table 3. Of course, the smallest stress can be observed in the air distance matrix: only the sphericity of the earth hampers the most perfect solution in this case. The speed differences of various network elements lead to higher stress of time distances, compared to network kilometer distances. This stress measures the deformation of the whole structure with one impressive number. However, the geographical decomposition of stress to particular points or pairs of points offers an extremely powerful method for geographical, spatial analysis.

Table 3: Value of stress-1 (six biggest Hungarian cities)

Distance	Stress-1
Shortest public road time distance by car	0,1335
Shortest public road kilometer distance	0,0844
Air distance	0,0086
Shortest time by rail (2009)	0,1361
Smallest cost by rail (2009)	0,1212
Smallest kilometer distance by rail (2009)	0,0859

Source: own calculation.

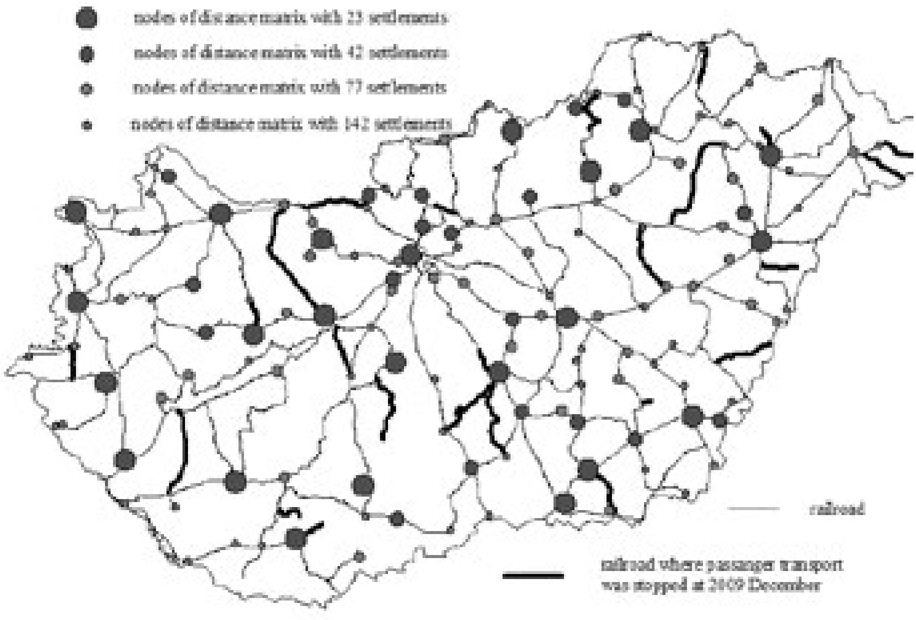
THE STUDY AREA AND DATA

In the empirical part of the paper, the spaces of the Hungarian railway network and public road network will be analyzed and compared to each other. The shortest road distance in kilometers, time distance in minutes for both networks and for the railroad, and the cost distance in Hungarian forint were completed. The source of railroad data is the timetable of the 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 (Budapest and the cities with county rights, without Érd), 42 points (the cities with county rights and other medium size cities) and 77 points (the cities of 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 in Figure 1. According to the new time schedule of December 2009, passenger transport was 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 also available on the reduced network.

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

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



Source: own figure.

RESULTS OF MULTIDIMENSIONAL SCALING

The 28 distance matrices were analyzed by the PROXSCAL technique of multidimensional scaling. The Stress-1 of 28 distance matrices can be seen in Table 4. Smaller values mean more even network and accessibility, without big differences between the various points of the network. The smallest value belongs to the public road network distance, which is a denser network than the railway network. The highest value is 0.213, thus the general configuration of distance matrices can be reproduced well or on an acceptable level in two-dimensional Euclidean spaces. In the case of time distances the stress is always higher, because of the different speeds of various parts of the network. The biggest network has higher stress in the case of railway time distance. The reason for this is that the smaller locations are not accessible with high-speed trains therefore the difference between average speeds is higher. The size of the network also has an impact on the results, but in a different manner for the time distance of railway and the 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.

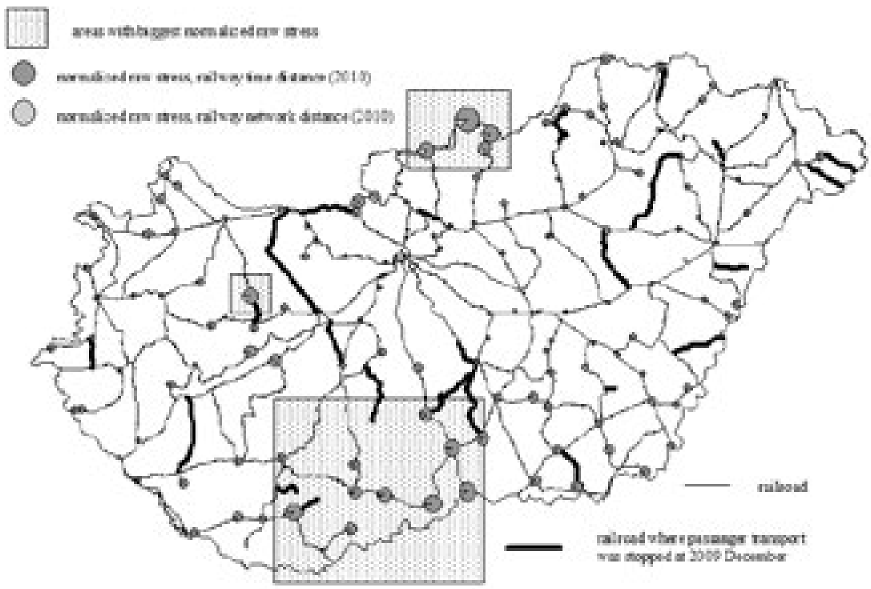
Table 4: Stress-1 measures of distance matrices

	23 nodes	42 nodes	77 nodes	142 nodes
Network distance, railway, 2009	0,095	0,092	0,094	0,096
Network distance, railway, 2010	0,099	0,099	0,099	0,100
Time distance, railway, 2009	0,142	0,156	0,148	0,176
Time distance, railway, 2010	0,149	0,164	0,154	0,205
Cost distance, railway, 2009	0,138	0,133	0,144	0,160
Network distance, public road	0,087	0,110	0,107	0,113
Time distance, public road	0,179	0,213	0,118	0,124

Source: own calculation.

It is interesting to analyze the decomposition of stress also. The contribution to stress by points can be seen in 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 is highly uneven. In the case of public road time distance, Hódmezővásárhely and Salgótarján have the biggest contribution to stress. Hódmezővásárhely can be explained by the absence of its position close to a main axis. In the case of Salgótarján the periferical location and the bad connection to Eger and Miskolc can be the explanation for the higher relative stress.

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



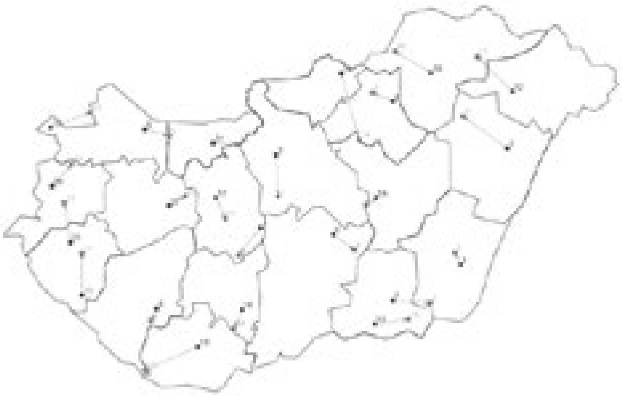
Source: own compilation.

RESULTS OF BIDIMENSIONAL REGRESSION

In this part only some general results will be presented in the form of various figures. For the sake of simplicity only the smallest network (with 22 nodes) will be depicted. Larger networks are more complex and harder to interpret. Graphical display is much richer in information than the quantitative display of the coordinates and their differences, because it shows the size and the direction of the change concerning all settlements. For example, it can be seen on every Figures that Budapest shifted in the direction of the centre of gravity, because its accessibility is better than its otherwise favourable, near-central geographical location.

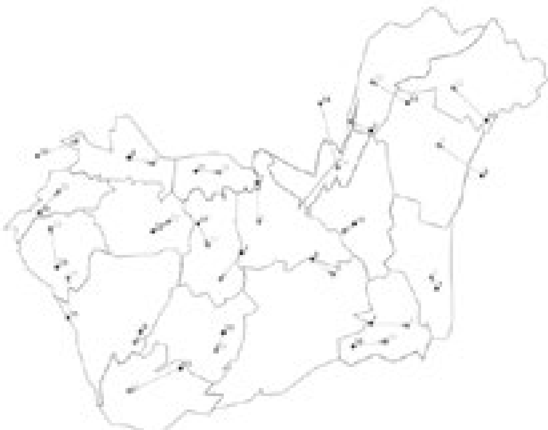
The calculations and graphical representation were conducted by program Darcy 2.0. (Downloadable from the homepage http://www.spatial-modelling.info/Darcy-2-module-de-comparaison) A description of the program can be read in Cauvin's paper (Cauvin, 2005). Figure 3 serves as a reference map, with the county borders of Hungary, with the cities with county right and with the adjusted coordinates of multidimensional scaling of railway network distance matrix. Figure 4 shows the railway network distance space. The origin of the vectors is the location of cities in geographical space; the end point is the location of cities in railway network space. The relative position of the cities in the railway network space was calculated with multidimensional scaling, the absolute position with the same coordinate system as the locations in geographical space was calculated with bidimensional regression. The deformation of county borders was calculated by interpolation, for the sake of further generalization and more visual information. Figures 5-8 show four different spaces, with the same methodology constructed.

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



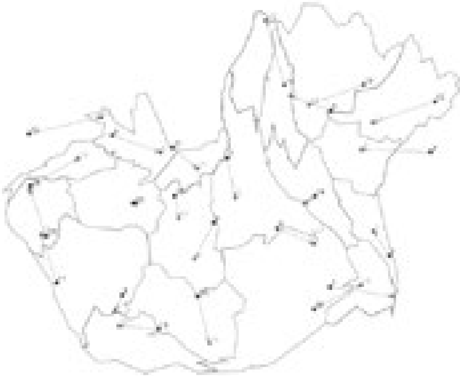
Source: own compilation.

Figure 4: Railway network distance space, 2010



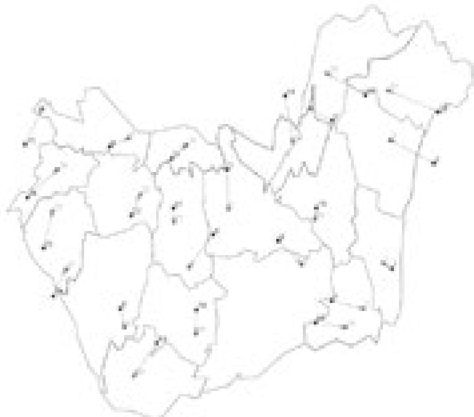
Source: own compilation.

Figure 5: Railway time distance space, 2010



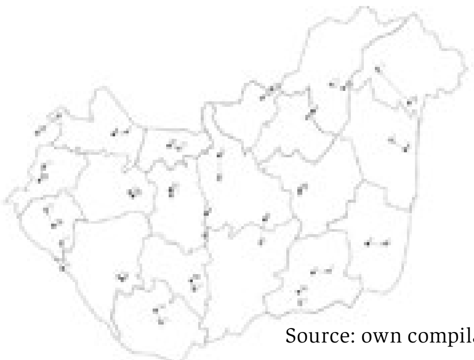
Source: own compilation.

Figure 6: Railway cost distance space, 2010



Source: own compilation.

Figure 7: Public road network distance space, 2009



Source: own compilation.

Figure 8: Public road time distance space, 2009

Source: own compilation.

There are two common characteristics of all maps. Firstly, the widening of the East-West distances in the Southern part of the country. The Danube has the biggest barrier effect in Hungary, South from Budapest there is just one railroad bridge and four public road bridges over the Danube, solving the East-West traffic. Secondly, space around Budapest is narrowed, because of the radial character of network, with Budapest in the centre. These two characteristics can be seen on Figure 6, where the displacement vectors of the transformed geographical 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 of 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 consist of nodes and lines.

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HUNGARIAN SUMMARY

A tanulmány a földrajzi, úthálózati, idő és költség távolságok alapján létrejövő különböző magyarországi terek közötti különbségeket vizsgálja. A bevezetést követően általános áttekintést ad a különböző terek sajátosságairól, majd a multidimenziós skálázás területi alkalmazhatóságával kapcsolatos néhány kérdést vázol. A multidimenziós skálázással készült tereket (közúti és vasúti hálózati és időteret, valamint a vasúti költségteret) a kétdimenziós regresszió segítségével teszi ábrázolhatóvá. Valamennyi nem földrajzi tér sajátossága az ország északi felének a kelet-nyugati irányok mentén történő viszonylagos zsugorodása, valamint a déli országrésznek a kelet-nyugati irányú szélesedése. Ez összhangban van az ország közlekedési hálózatának ismert jellemzőivel.

Chapter Hill