NEW TIME-SPACE MAPS OF EUROPE

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Résumé

Increasing mobility is one of the constituting features of modernity. Today, Europe is facing a new thrust of acceleration : the planned european high-speed rail network will open up new dimensions on travel speed and so of the relation of space and time.

The topic of the paper is the visualisation of the new relationship of space and time by a new type of maps. These time-space maps do not display distances but time distances between cities and countries. For this purpose a method for creating time-space maps has been developed, which improves current methods and avoids their pitfalls. To demonstrate the developed method, time-space maps for Europe, France and Germany are presented.

Mots Clés

Computer-based cartography - Europe - France - High-speed transport networks - Time-space maps

1. Introduction : Space and Time

At the beginning of the era of the railways, Heinrich Heine wrote in Paris : «The railway kills space, so we are left with time. If we only had enough money to kill time, too ! It is now possible to go to Orléans in four and a half hours or in as many hours to Rouen. Wait until the lines to Belgium and Germany are built and connected with the railways there ! It is as if the mountains and forests of all countries moved towards Paris. I can smell the scent of German linden trees, and the North Sea is roaring in front of my door» (Heine, 1854, 65). The quotation circumscribes the topic of this paper, the relationship between speed and space or, in other words, the relationship between space and time.

Following the theory of time-space geography (Hägerstrand, 1970), increasing speed may be transformed either in a greater amount of free time or in a larger action space. Empirical studies of mobility have shown that the individual daily time budget for transport is relatively constant (Zahavi, 1979). So free time gained by higher speed is often used to travel more frequently or to more distant locations. A constant time budget thus leads to a shrinking of space in the subjective perception of the individual.

Increasing mobility is one of the constituting features of modernity : «The history of modern societies can be read as a history of their acceleration» (Steiner, 1991, 24). Modern society is a society of centaurs, creatures with a human front and an automobile abdomen (Sloterdijk, 1992). Today Europe is facing a new thrust of acceleration : The planned European high-speed rail network (Community of European Railways, 1989) will open up new dimensions of travel speed and so of the relation of space and time.

The topic of the paper is the visualisation of the new relationship between space and time by a new type of maps. These time-space maps do not display spatial distances but time distances between cities and countries. A method for creating time-space maps has been developed which improves current methods and avoids their pitfalls. To demonstrate the method, time-space maps of western Europe and France showing the effects of the evolving European high-speed rail network are presented.

2. Current Methods for Creating Time-Space Maps

Time-space maps represent the time space. The elements of a time-space map are organised in such a way that the distances between them are not proportional to their physical distance as in topographical maps, but proportional to the travel times between them. Short travel times between two points result in their presentation close together on the map ; points separated by long travel times appear distant on the map. The scale of the map is no longer in spatial but in temporal units. The change of map scale results in distortions of the map compared to physical maps if the travel speed is different in different parts of the network. If one assumes equal speed for all parts of the network, the result is the familiar physical map. Time-space maps with equal speeds can be used as reference for the interpretation of other time-space maps. They are called *base maps* here. All base maps in this paper use a homogenous travel speed of 60 km/h and have the same time scale as their associated time-space maps. Time-space maps may include all elements of normal maps such as coast lines or borders, transport networks or single buildings. In practice only elements relevant for understanding the map are displayed. The emphasis is on the distortions of time-space maps compared with physical maps or with other time-space maps.

Time-space maps are created by transforming physical coordinates of a physical map into time-space coordinates. This can be expressed in global terms as follows :

$$u = f(x,y) \qquad v = g(x,y) \qquad (1)$$

Here (x,y) are the coordinates of a point on the physical map, (u,v) the coordinates of that point on the time-space map, and *f* and *g* are transformation functions. The functions are calibrated in such a manner that the distance between points i and j on the time-space map,

$$\text{dij} = \sqrt{(u_i - u_j)^2 + (v_i - v_j)^2} \qquad 2$$

is in as close agreement as possible with the time distance t_{ij}.

Because there are different speeds in the network, it is not possible to exactly reproduce the time distances of a time-space map in two dimensions. This would require a coordinate space with more dimensions. Time-space maps therefore can only be approximate.

2.1. Multidimensional Scaling (MDS)

Usually the technique of multidimensional scaling (MDS) is used for generating time-space maps. If the differences between a set of phenomena in one dimension (in metric or non-metric units) are known, the MDS technique generates a spatial configuration in multidimensional coordinate space of additional attributes of the phenomena such that the distances between the items are as close as possible to the known distances. The MDS approach was developed in psychometrics in order to analyse, for instance, similar or different reactions of persons on multiple stimuli through visualisation in multidimensional space.

Time-space mapping is an example of applying metrical MDS. If t_{ij} is the travel time and d_{ij} the distance between two points i and j, all points are configured in two-dimensional space such that

$$\min_{u,v} \sum_{i<j} (t_{ij} - d_{ij})^2 \qquad (3)$$

There are several MDS algorithms differing by the optimisation procedure used. The transformation functions of equation (1), however, always have the form

$$u_i = x_i + a_i \qquad v_i = y_i + b_i \qquad (4)$$

i.e., the time-space coordinates are calculated by adding point-specific offsets in X- and Y-direction to the physical coordinates. The application of MDS for the generation of time-space maps is further explained in Haggett (1983) and Gatrell (1983).

2.2. Interpolation

The result of MDS is a configuration in which the distances between the calibration nodes correspond as closely as possible to the known travel times. The calibration points may represent cities or other places, but they do not represent a complete map. Other map elements such as coast lines or borders have to be added. The time-space coordinates of the additional elements are not generated by MDS but by interpolation.

As shown above, the output of MDS are displacement vectors or offsets in X- and Y-direction. These vectors indicate for each calibration node the transformation from physical to time-space coordinates. Offsets of additional map elements can be calculated by interpolation between the offsets of adjacent calibration nodes. This is normally done by calculating the mean of the offsets of the closest calibration nodes weighed by their distance (see, for instance, Ewing and Wolfe, 1977).

2.3. A New Method

A time-space map generated as explained above is based on a number of calibration nodes, their offsets are determined by MDS, and the coordinates of additional map elements are calculated by interpolation. However, there are two problems associated with this method (see Tobler, 1978 and Shimizu, 1992) :

– MDS locates calibration nodes only on the basis of travel times and does not take the topological features of the map into account. Therefore MDS may result in a distortion of the topology. For instance, it is possible that certain areas are mirrored or folded over other areas, even though the map may represent an excellent solution of the objective function of the optimisation.

– The second problem is caused by the interpolation method, in which a weighted mean of offsets of nearby calibration nodes is calculated. This can lead to sudden discontinuities in the transformation. For example, if along a coast line one calibration node is replaced by another with a different offset, a jump in the coast line may occur. Such leaps may lead to faults in the map, which may be misinterpreted as large time distances between points.

To overcome these deficiencies, modified methods for calibration and interpolation were developed (Spiekermann and Wegener, 1993).

2.4. Stepwise Multidimensional Scaling (SMDS)

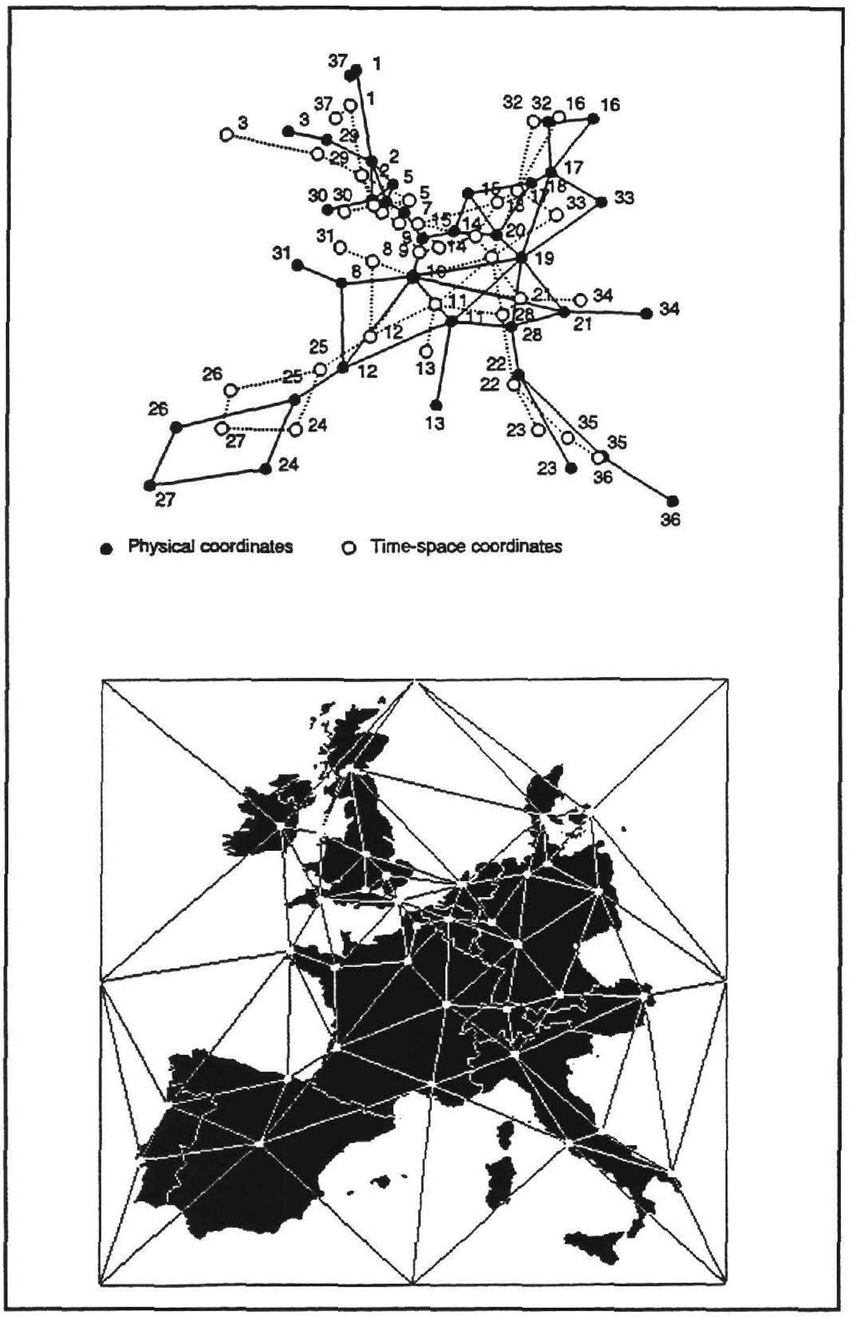
MDS achieves an optimal configuration of calibration nodes in two-dimensional time space, i.e. a configuration in which the map distances between the calibration nodes are as proportional as possible to the known travel times. However, there may be serious distortions of the map topology in the form of faults and wrinkles of the map surface where fast and slow elements of the network meet.

The solution to this problem is to apply MDS *stepwise* on ring-shaped segments of the calibration network and to permanently fix the calibration nodes of each round. This modification of MDS is called stepwise multidimensional scaling (SMDS). Stepwise multidimensional scaling starts with an origin node specified by the user. The coordinates of this node remain unchanged. In the first round all nodes of the calibration network that are directly connected to the origin node are processed. The X- und Y-coordinates of these nodes are the parameters to be optimised. The calibration network of the first round consists of all links between the origin node and these nodes and all links between them.

After completion of the first round the time-space coordinates of the nodes of the current calibration network are permanently fixed. The calibration nodes of the second round are all nodes which are directly connected with the nodes of the previous round. The calibration network of the second round consists of all links between the nodes of the first round and the new nodes and all links between the latter. Before entering the optimisation, the new calibration nodes are relocated so that their direction from the node of the previous round they are connected with and their distance from that node (in terms of travel time) remain unchanged. In other words, the initial values of the coordinates of the new round are set in such a way that the extension of the time-space network follows the direction of its extension on the physical map. In this way the probability of topological distortions is minimised. After the optimisation, the new calibration nodes of the second round are also fixed.

The subsequent rounds are processed correspondingly until all nodes of the calibration network are fixed. In this way the calibration network is processed from the inside out in ring-shaped segments. The advantage of the stepwise approach is that by choosing the origin node it can be decided which parts of the map should be stable and in which direction the distortion should take place. This avoids undesired topological distortions but does not level off true map distortions. So SMDS results in a much more easily understandable map representation. Figure 1 (top) shows the result of SMDS for the rail network of western Europe in physical (black) and time-space (white) coordinates.

Figure 1 : Calibration network of western Europe : results of stepwise multidimensional scaling (top) and triangulation (bottom)



2.5. Interpolation with Triangulation

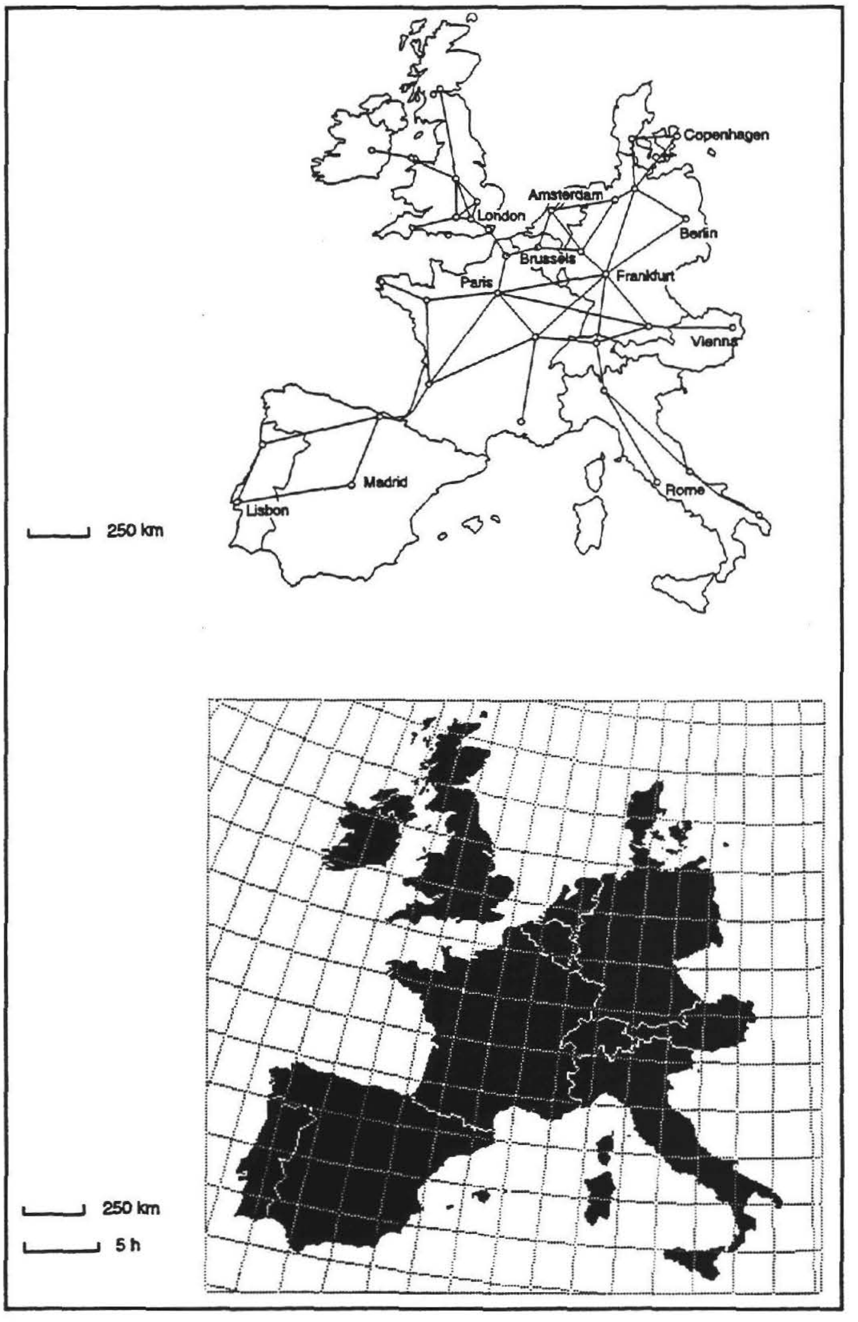
To avoid the jumps in coast lines and borders caused by the instability of the interpolation method, an interpolation method based on triangulation as applied in digital terrain modelling was adopted. A triangulation of a group of points is a triangular mesh with the points as corners and minimum total length of edges. In digital terrain modelling triangulation is used to interpolate contour lines between irregularly spaced points with known elevation. In analogy to this, triangulation is applied here for the interpolation of points between calibration nodes with known offsets. Figure 1 (bottom) illustrates the triangulation for the rail network of western Europe.

Because the triangulation covers the entire map area, each point on the map, i.e. each point of the coast lines and borders and of the geographical grid, can be allocated to a triangle, for which the offsets of the corners are known. The offsets of a point are calculated as the weighted average of the offsets of the three corners of the triangle in which it is located. The averaging is done for the X- and Y-directions separately. The averaging consists of determining the intersection between the triangle surface and a vertical line at the point in question. This method avoids jumps in the interpolated lines.

3. Results

This section presents time-space maps of western Europe and France produced with the method described above. The time-space maps visualise the impacts of recent and future improvements of the evolving high-speed rail network in Europe on the time space of the continent.

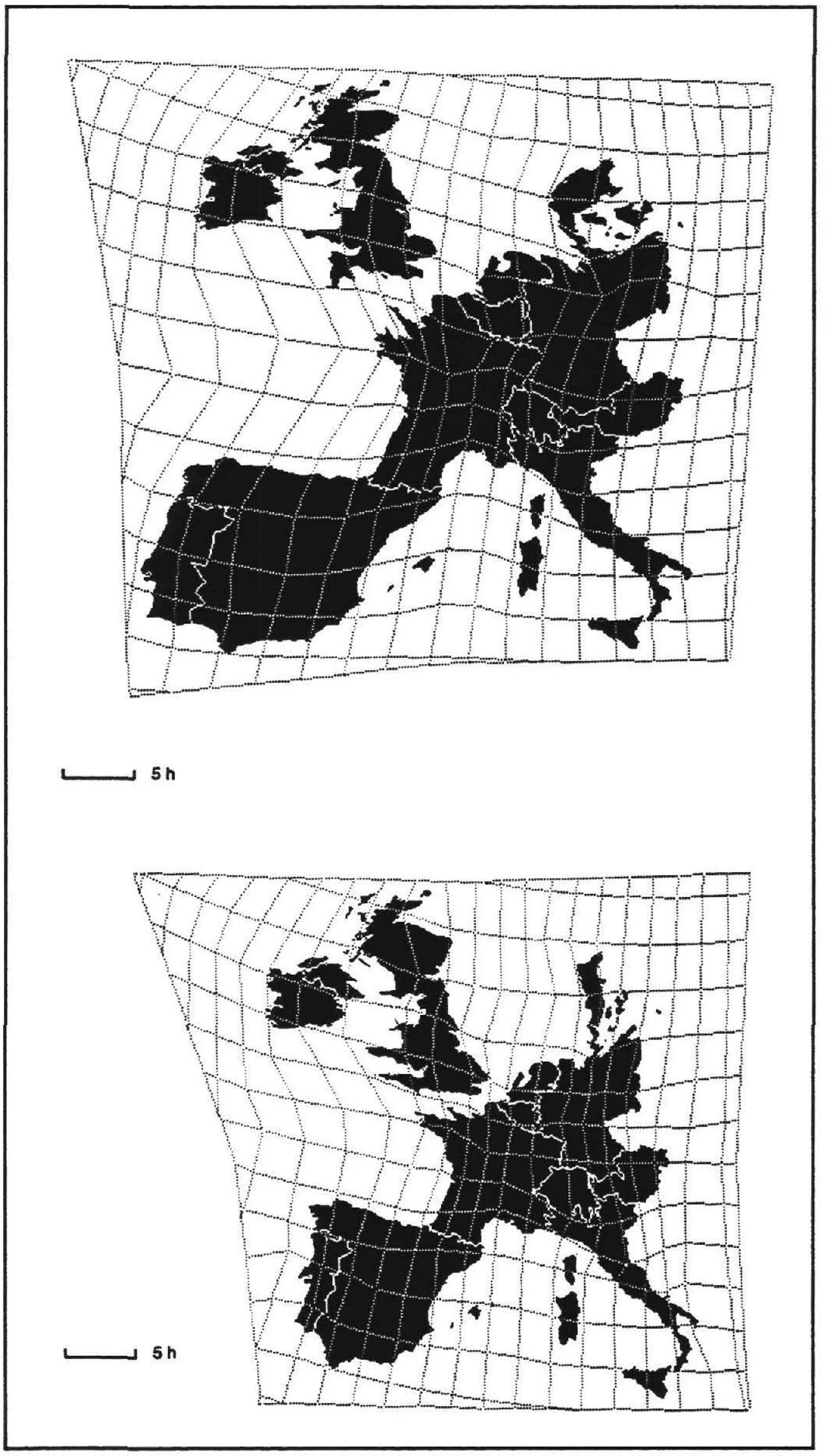
Figure 2 : Calibration network (top) and 60 km/h base map (bottom) of western Europe



3.1. Western Europe

Figures 2 and 3 illustrate the impacts of rail infrastructure improvements on the time space of western Europe. The network was reduced to the base network of Figure 2 (top) used already in Figure 1. For this network travel times were collected from time tables and forecast for different points in time (ACT Consultants et al., 1992 ; Fayman et al., 1992). The following infrastructure scenarios were considered :

Figure 3 : Time-space maps of the rail network in western Europe, 1991 (top) and 2010 (bottom)



– Rail network 1991 : In 1991 the European high-speed rail network consists only of one link, the TGV between Paris and Lyon. All other parts of the network are operated at lower speeds.

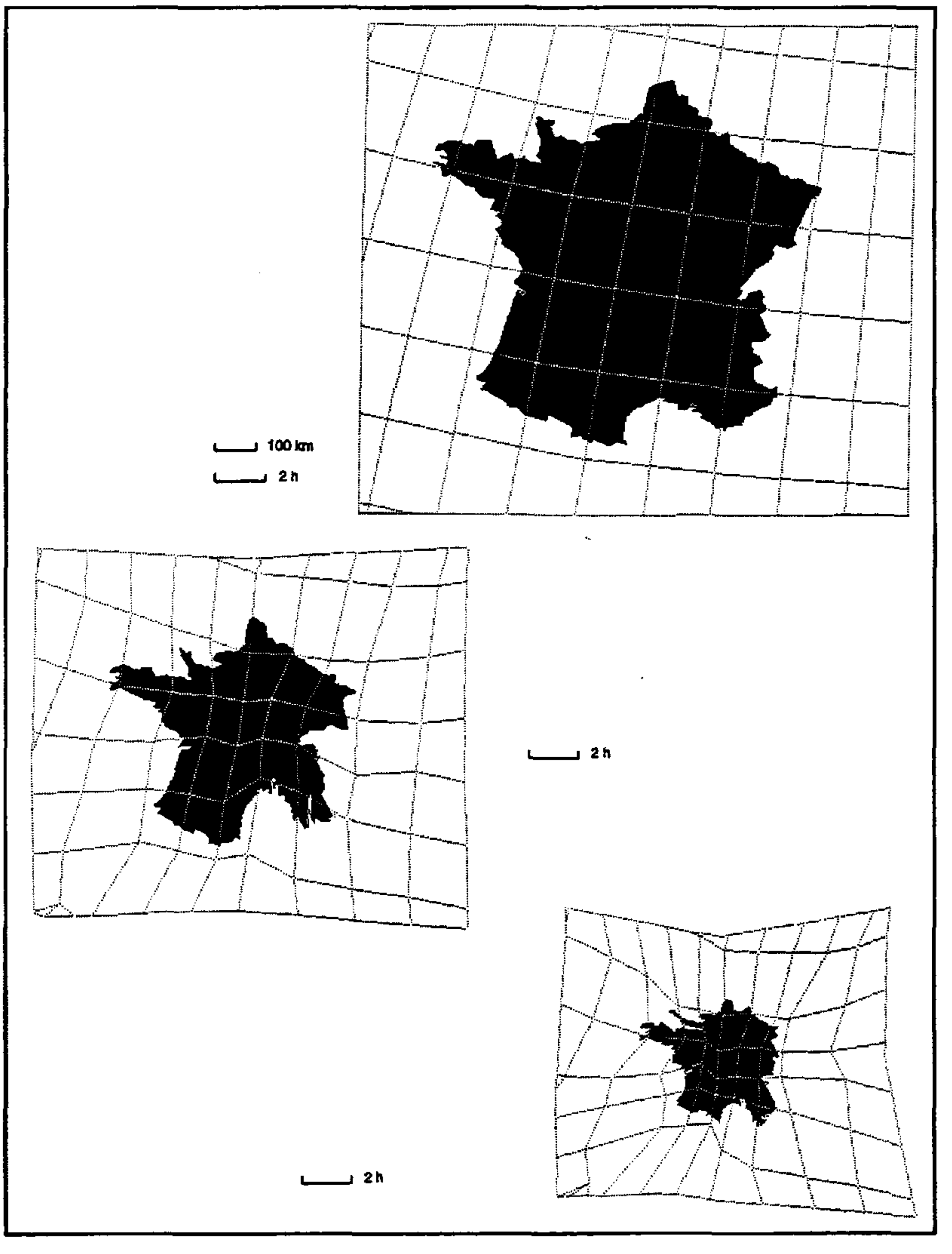
– Rail network 2010 : The rail network in 2010 will contain the high-speed rail links already in operation since 1991, the TGV Atlantique in France and the ICE Hamburg-Munich in Germany, and future links such as the TGV Nord, the TGV Méditerranée, the TGV Est and the new ICE links Cologne-Frankfurt and Berlin-Hamburg as well as links to and within Spain and Italy. The most important changes in the European rail network are the opening of the Channel Tunnel in 1994 and the direct high-speed rail links from Paris and Brussels to London.

The impacts of these scenarios on the time space of western Europe are presented in Figure 3 ; Figure 2 (bottom) shows the base map as reference. The base map refers to an air-line speed of 60 km/h and has the same time scale as the following time-space maps. Figure 3 shows that the impacts of the new high-speed rail lines are substantial. Even in 1991 (Figure 3, top), France was contracted by the first TGV between Paris and Lyon, whereas Spain and Portugal appear larger and Great Britain and Ireland are pushed towards the periphery. The full 'space eating' effect of high-speed rail becomes visible with the implementation of the high-speed rail network by 2010 (Figure 3, bottom) : The continent has been reduced to half its original size. The southern parts of England are pulled to the continent by the Channel Tunnel, whereas Ireland and the north of Scotland remain peripheral. The Alps remain a major barrier in the core of Europe, because in this scenario the Alpine base tunnels are not assumed to be built.

3.2. France

Figure 4 shows the effects of different stages of implementation of the French TGV network. Origin node of the stepwise multidimensional scaling of these maps is Paris. Figure 4 (top) is the base map with a speed of 60 km/h. The middle part shows a time-space map of France based on travel times between seventy French cities and Paris in 1988/89 (SNCF, 1991). The contraction of the hexagon along the TGV Paris-Lyon is visible. The difference in size compared with the base map indicates that even without the TGV the average speed is much higher than 60 km/h. When the plans of the French government for the TGV (SNCF, 1991) will be implemented, the shrinking of the hexagon will be much more dramatic (Figure 4, bottom). This plan contains 4,700 km of high-speed lines, of which 700 km are currently in operation. After implementation of the scheme, all important regional centres will be reached from Paris in less than three hours, all borders in less than four hours. Return trips on the same day to London, Amsterdam, Cologne, Frankfurt, Munich, Zurich, Milan or Barcelona will become feasible with a maximum travel time of four and a half hours one way.

Figure 4 : Time-space maps of the rail network in France, 60 km/h base map (top), 1988/89 (middle) and 2010 (bottom)



4. Conclusions

The method of creating time-space maps presented in this paper avoids the disadvantages of current approaches by stepwise multidimensional scaling and interpolation with triangulation. Using this method, time-space maps with a high correspondence between map distances and travel times, yet without undesirable distortions of topology can be produced. By the selection of the origin node the direction of the map distortion can be influenced.

France with the shape of France within Europe in Figure 3 indicates that the appearance of time-space maps is significantly influenced by the underlying calibration network.

The visualisation of the effects of new high-speed links in time-space demonstrates the shrinking of the European continent or of countries like France. However, high-speed infrastructure connects only important cities, but not the space in between them. This generalisation hides that the regions in between might become new peripheralised zones, in which accessibility is decreasing in relative or even in absolute terms through the elimination of interim stops, when high-speed trains are introduced.

Time-space maps, applied with judiciousness and responsibility, are an interesting medium for the visualisation of spatial change. In a period in which new and faster transport modes fundamentally change the relationship between space and time, time-space maps can be used to gain a better understanding of the change processes at work and of the destruction of space by increasing spatial mobility and of its social and ecological costs.

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