The shrinking continent: new time – space maps of Europe

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The shrinking continent: new time-space maps of Europe

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Abstract. Increasing mobility is one of the constituent features of modernity. Today Europe is facing a new thrust of acceleration: the planned European high-speed rail network will open up new dimensions of travel speed and so of the relation of space and time. The topic of this paper is the visualisation of the new relationship of space and time by a new type of map. 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 this method, time-space maps of Europe and selected European countries showing the effects of the evolving European high-speed rail network are presented.

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" (1854, page 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.

According to the theory of time-space geography (Hägerstrand, 1970), increasing speed may be transformed either into a greater amount of free time or into 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 constituent features of modernity: "The history of modern societies can be read as a history of their acceleration" (Steiner, 1991, page 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 map. 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 upon current methods and avoids their pitfalls. To demonstrate the method, time-space maps of Europe and selected European countries showing the effects of the evolving European high-speed rail network are presented.

Visualisation of space and time

There are different methods to display the interrelation of space and time on a map. Three types of maps can be distinguished.

Isochrone maps show temporal relations in space by preserving the spatial distances between map elements. Isochrone maps display areas of similar travel time to one selected point on the map. By drawing lines of equal travel times (isochrones) from the selected point, the travel time from all points of the map to the selected point in a given network or transport mode becomes visible. An isochrone far from the next one indicates fast transport; isochrones close to the next one display long travel times. In this way isochrone maps permit one to judge the quality of the transport infrastructure. The disadvantage of isochrone maps is that only travel times from one single point can be displayed; travel times between other points of the map cannot be read from the map.

Cognitive maps visualise the temporal efforts of travel by associative illustrations that are not exact in cartographic terms. Cognitive maps are subjective interpretations of reality (Downs and Stea, 1977). A cognitive maps reflects the world in a way a person believes that it is like; the map does not need to be exact. The probability of distortion is high. The shapes of coastlines and borders may change, proportions between different areas may not be exact, topological relations of places may differ from reality. Because cognitive maps represent subjective perceptions of the world, they are often used for advertisements. By exaggerating certain elements, a positive effect can be achieved, for example by exaggerating the speed of transport modes or by changing spatial relations in favour of certain places.

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 is no longer in spatial but in temporal units. The change of scale results in distortions of the map compared with 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 references 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^{-1} and have the same time scale as their associated time-space maps. Time-space maps may include all elements of normal maps such as coastlines 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 or with other time-space maps.

Current methods for creating 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:

$$u = \mathrm{f}(x, y)\,, \quad v = \mathrm{g}(x, y)\,. \tag{1}$$

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,

$$d_{ij} = [(u_i - u_j)^2 + (v_i - v_j)^2]^{1/2}\,, \tag{2}$$

is in as close an agreement as possible with the time distance t_{ij}. In figure 1 we explain the principle of time-space mapping with a simplified example.

Because there are different speeds in the network, it is not possible to reproduce exactly 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.

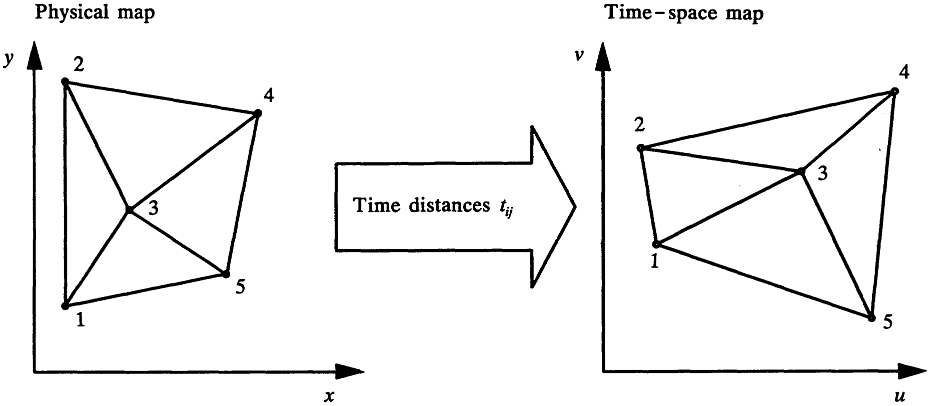


Figure 1. Principle of time-space mapping.

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 nonmetric 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 to 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

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

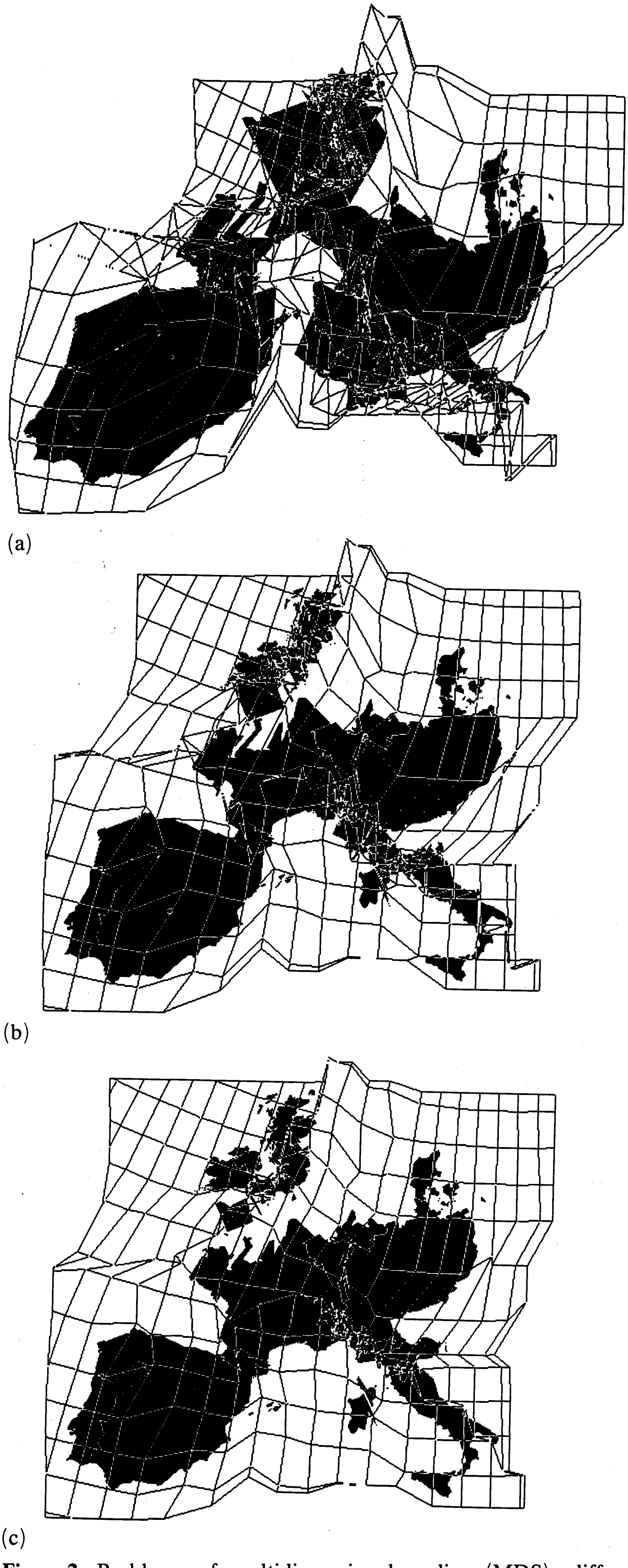
There are several MDS algorithms which differ according to the optimisation procedure used. The transformation functions of equation (1), however, always have the form

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

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

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



(a)

(b)

(c)

Figure 2. Problems of multidimensional scaling (MDS): different number of interpolation nodes: (a) 3, (b) 6, (c) 9.

points may represent cities or other places, but they do not represent a complete map. Other map elements such as coastlines 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 the *X*- and *Y*-directions. 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 (for instance, see Ewing and Wolfe, 1977).

Problems

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 (Tobler, 1978; see also Shimizu, 1992):

(1) 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 two streets which in reality are parallel, cross on the time-space map, or 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.

(2) 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 coastline one calibration node is replaced by another with a different offset, a jump in the coastline may occur. Such leaps may lead to faults in the map, which may be misinterpreted as large time distances between points.

To illustrate these problems, figure 2 displays a series of time-space maps of western Europe generated by the above method. The number of adjacent calibration nodes used for the interpolation of coastlines and borders was increased stepwise from 3 [figure 2(a)] to 9 [figure 2(c)]. In each case the topology is distorted. Even on the most stable map [figure 2(c)] a 'new island' is drawn in the western part of the British Channel. In the other two maps the distortions of topology are aggravated. Jumps generated by the interpolation method can be observed, for instance, at the northeastern border of Portugal. For this part of the border one or more calibration nodes are substituted by other nodes. The inclusion of more nodes reduces the effects of single nodes. However, this results in the elimination of local features so that the time-space map becomes more and more similar to the physical map. So a new problem arises, the selection of an appropriate number of nodes for the interpolation.

A new method

To tackle these problems, Shimizu (1992) proposed an extension of the MDS technique preserving the topological properties and eliminating the interpolation step by applying quadratic, cubic, or polynomial transformations to *all* map elements. His method led to impressive time-space maps of Japan. However, attempts to apply topological transformations to a time-space map of France revealed that topology-preserving transformations were too continuous, that is, they levelled off local distortions (Spiekermann and Wegener, 1993). To overcome these deficiencies, modified methods for calibration and interpolation were developed.

Stepwise multidimensional scaling (SMDS)

MDS achieves an optimal configuration of calibration nodes in two-dimensional time-space, that is, 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.

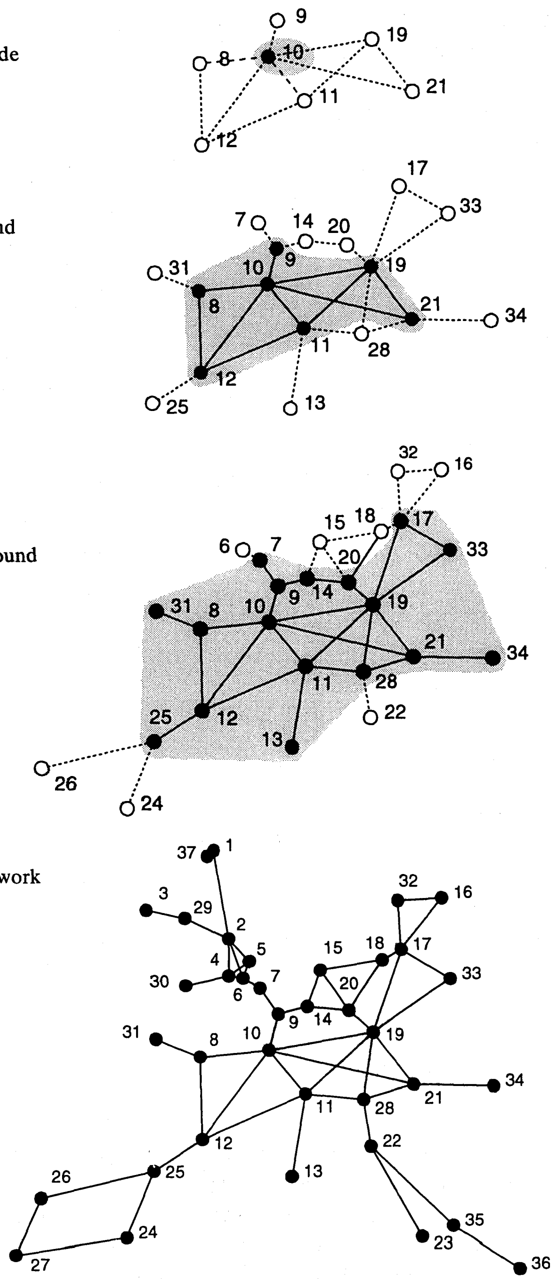


Figure 3. Principle of stepwise multidimensional scaling (SMDS).

The solution to this problem is to apply MDS *stepwise* on ring-shaped segments of the calibration network and to fix the calibration nodes of each round permanently. 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*- and *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 3 displays the stepwise processing of calibration nodes in ring-shaped segments for the rail network of western Europe. The origin node is Paris (node 10). Figure 4(a) (see over), shows the result of SMDS for the rail network of western Europe in physical (black) and time–space (white) coordinates.

Interpolation with triangulation

To avoid the jumps in coastlines 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 4(b) illustrates the triangulation for the rail network of western Europe.

Because the triangulation covers the entire map area, each point on the map, that is each point of the coastlines 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. Figure 5(a), displays the interpolated offsets of coastlines and borders and figure 5(b) the intersections of the geographical grid in western Europe.

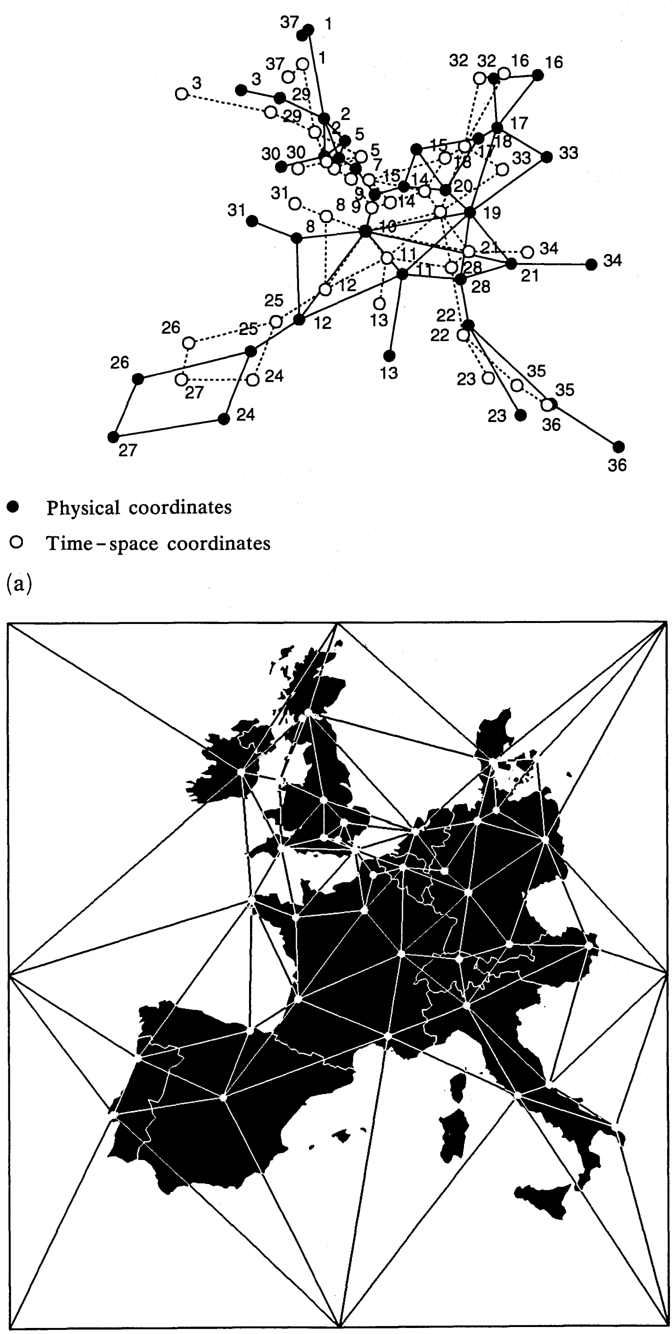
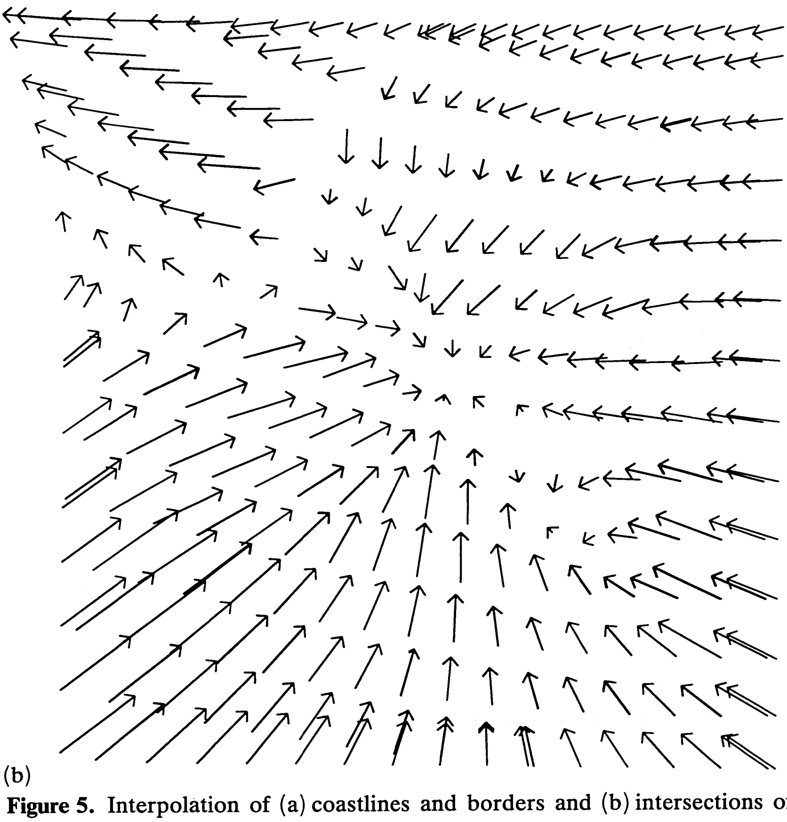


Figure 4. Calibration network of western Europe: results of (a) stepwise multidimensional scaling and (b) triangulation.

(a)



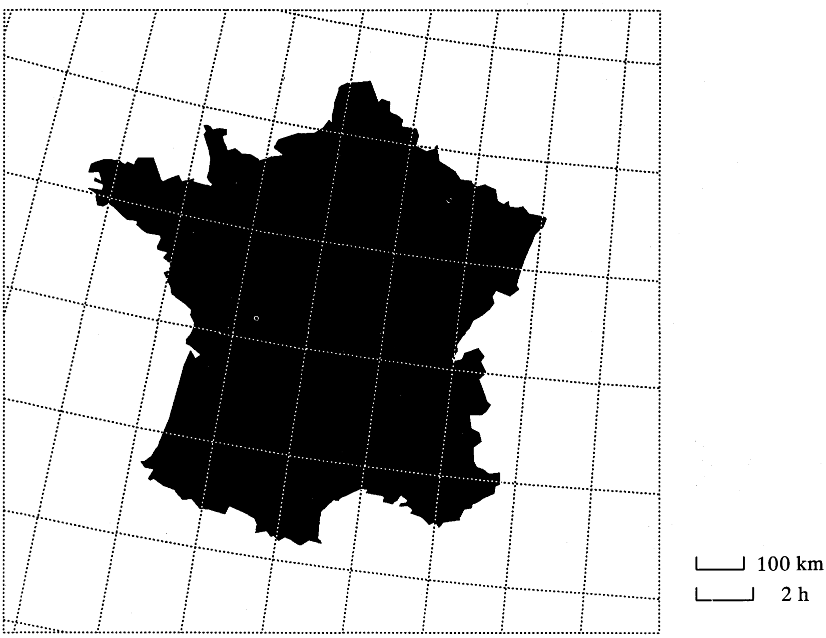
(b)

Figure 5. Interpolation of (a) coastlines and borders and (b) intersections of the geographical grid.

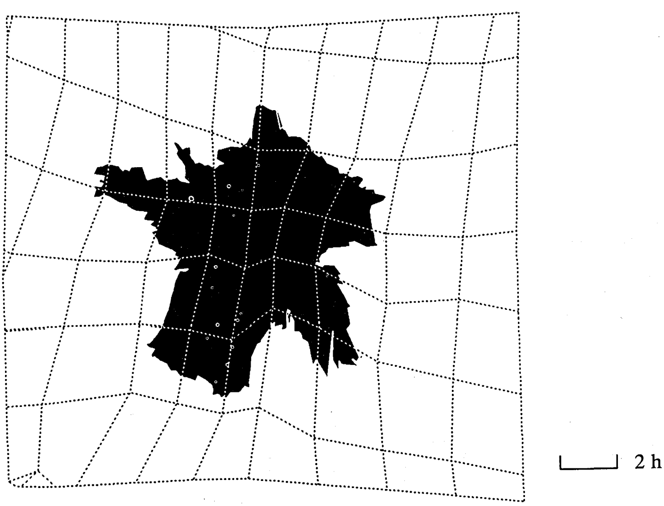
Results

In this section we present time-space maps of Europe and of selected European countries 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 using four examples:

(a) The first example is France, because the first high-speed train in Europe was the TGV, and the French high-speed rail plans are the most ambitious in Europe.



(a)



(b)

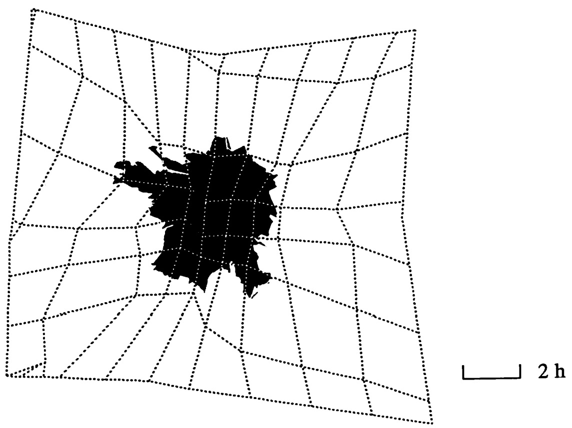
Figure 6. Time-space maps of the rail network in France: (a) 60 km h^{-1} base map and (b) journeys to Paris, 1988.

(b) The second example is Germany. The German high-speed train, the Intercity Express (ICE), has been in operation since 1991. Germany is also of interest because of the reintegration of the formerly separated rail networks of West and East Germany.
(c) The third example shows the evolution of the rail network of western Europe, that is, of the European Union plus Austria and Switzerland.
(d) In 1992 the International Union of Railways (UIC) outlined a high-speed rail network including eastern and northern Europe. The consequences of this network for the time-space of Europe are shown in the last example.

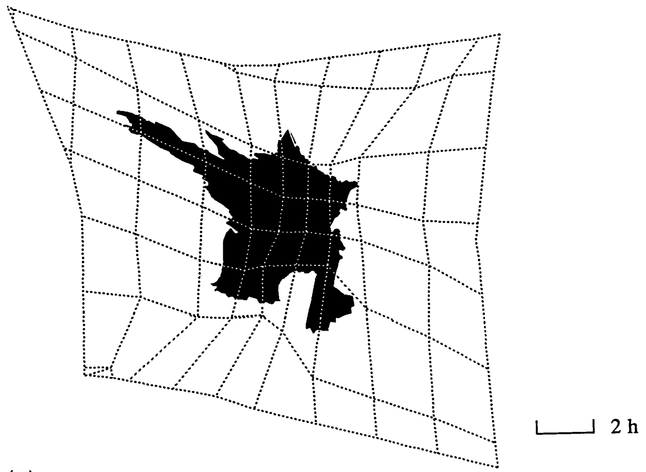
France

Figures 6 and 7 show the effects of different stages of implementation of the French TGV network. The origin node of the stepwise multidimensional scaling of these maps is Paris.

Figure 6(a) is the base map with a speed of 60 km h^{-1}. Figure 6(b) shows a time-space map of France based on travel times between seventy French cities and



(a)



(b)

Figure 7. Time-space maps of the rail network in France in 2010 for (a) journeys to Paris and (b) between regional centres.

Paris in 1988 (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^{-1}.

When the plans of the French government for the TGV (SNCF, 1991) are implemented, the shrinking of the hexagon will be much more dramatic [figure 7(a)]. This plan contains 4700 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.

The future TGV network, which originally was mainly oriented towards Paris, will also enable quick journeys between regional centres through the Paris bypass and TGV lines such as Rhine–Rhone (Mulhouse–Lyon) or Grand Sud (Bordeaux–Narbonne). Figure 7(b) presents a time–space map for France based on twenty-eight such regional links. With the exception of parts of Britanny and the far southeast of France, all regional centres are linked to each other in less than five hours. This might lead to a reduction of the dominance of the French capital.

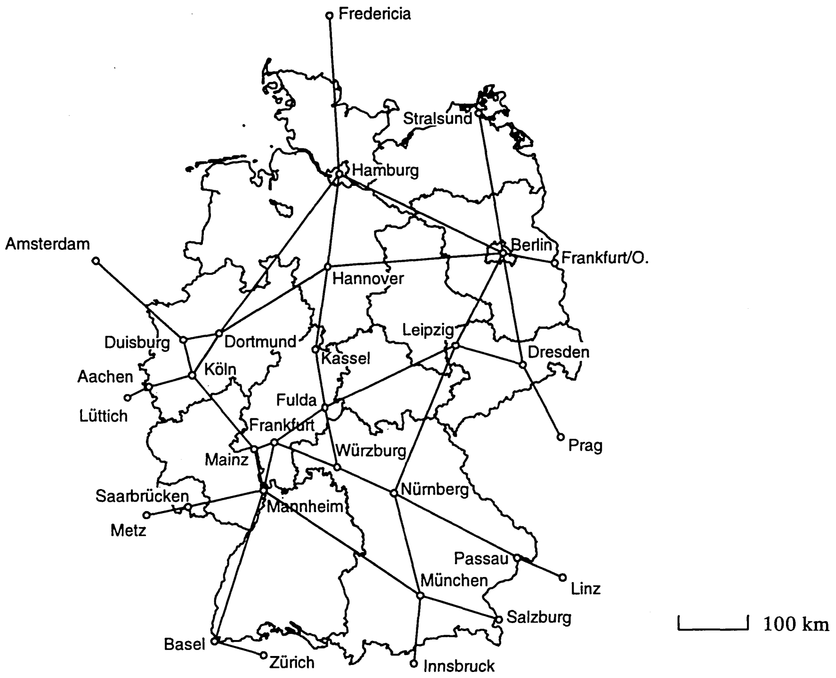
Germany

Figures 8–10 show the calibration network, the triangulation, the base map, and three time–space maps for the German rail network. The origin node of the stepwise multidimensional scaling of these maps is Frankfurt.

Figure 8(a) shows the base network of the German Intercity and ICE lines and the most important links to neighbouring countries. Figure 8(b) displays the triangulation of the calibration nodes. Figure 9(a) (see over) is the base map representing an air-line speed of 60 km h^{-1}. Figure 9(b) is based on the rail travel times of 1985. It shows that in 1985 train journeys in the GDR were much slower than in West Germany and that the links between East and West Germany were slowed down by long stops at the intra-German border. Because of the long travel times between Bavaria and the GDR the whole territory of the GDR is pushed towards the northeast.

Figure 10(a) (see over) shows the current situation. The operation of the first ICE line between Hamburg and Munich since 1991 has led to a further shrinking of west Germany. The new Länder have come somewhat closer because of the elimination of stops at the former border and the restoration of east–west rail links. However, the rail network in the former GDR has not yet been accelerated so that the time–space disparity between the western and eastern parts of the country has become even more pronounced. This will change when, as assumed in figure 10(b), the planned rail improvements are implemented in the next century. Then rail speeds in east and west Germany will be equal so that the time–space map of Germany will again look like the base map, though much smaller. It is interesting to note that the French time–space maps [figure 6(b) and figure 7] are shrinking more than their German counterparts. This indicates that the German railways are slower than the French railways and that this difference will continue to exist in the next century.

The time–space maps of figures 9 and 10 can also be regarded as visualisation of a fusion of two time regimes (Baier, 1990; Stiens, 1992). The Berlin Wall not only separated the population of East Germany from the world, but at the same time protected a zone of relaxed time. West Germany, in contrast to this, was a zone of compressed time. By the transport projects of 'German Unity' the new Länder are 'elevated' to the zone of compressed time.



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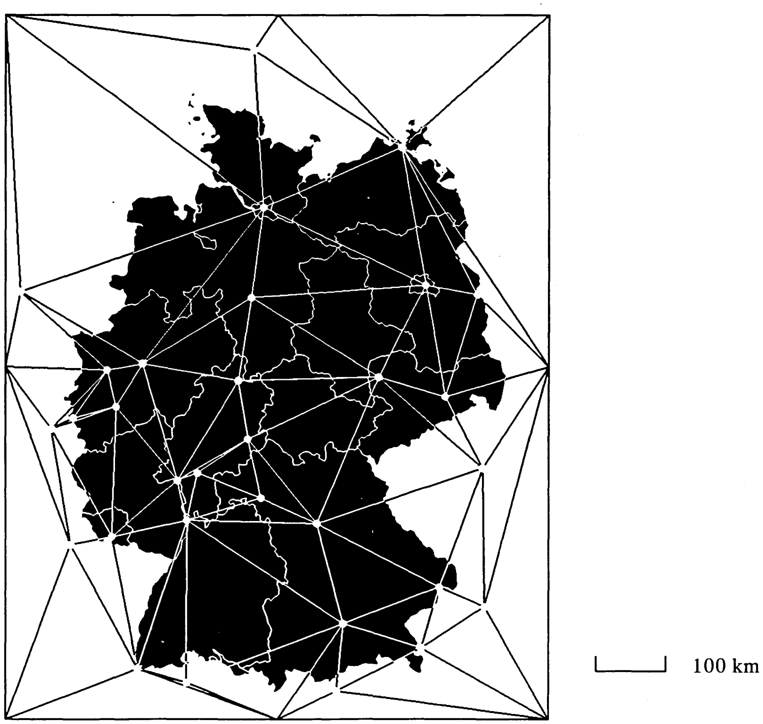


(b)

Figure 8. (a) Calibration network and (b) triangulation of the German rail network.

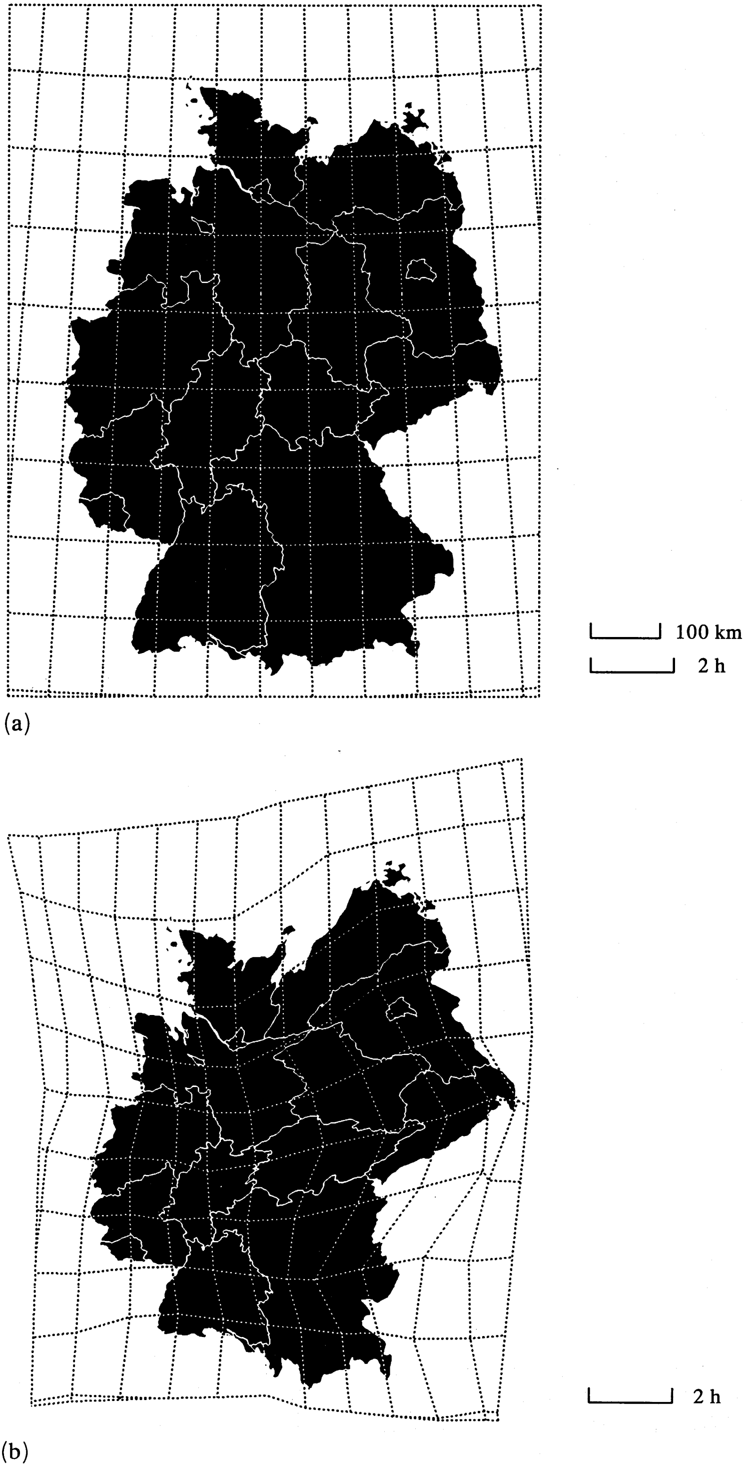


Figure 9. (a) 60 km h^{-1} base map and (b) time–space map of the rail network in Germany, 1985.

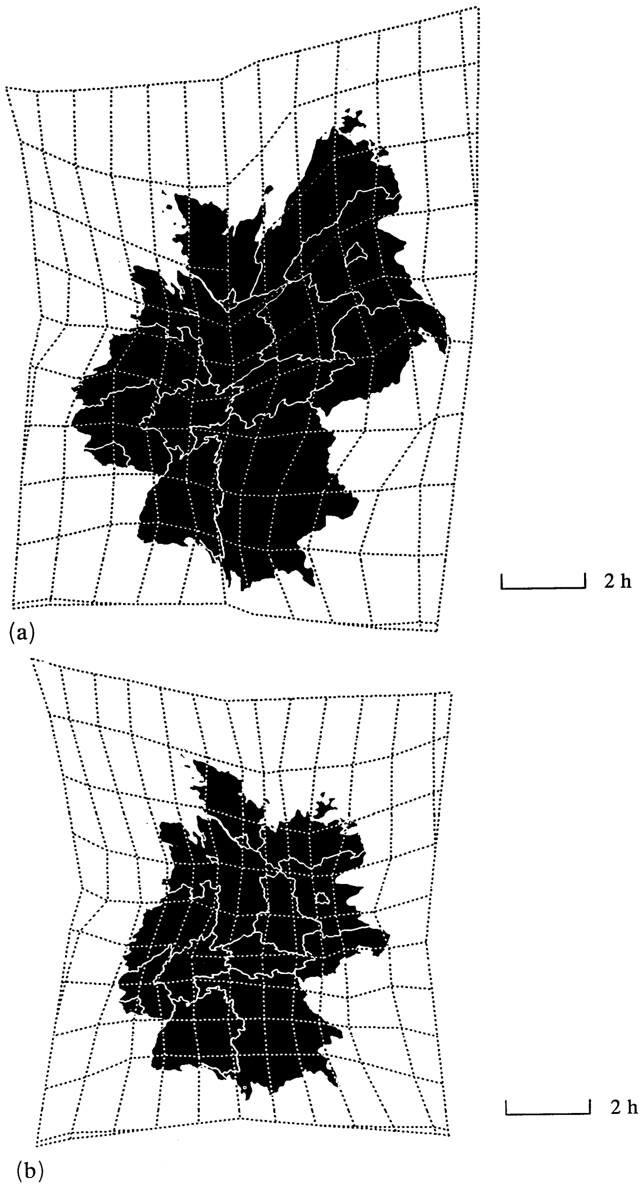


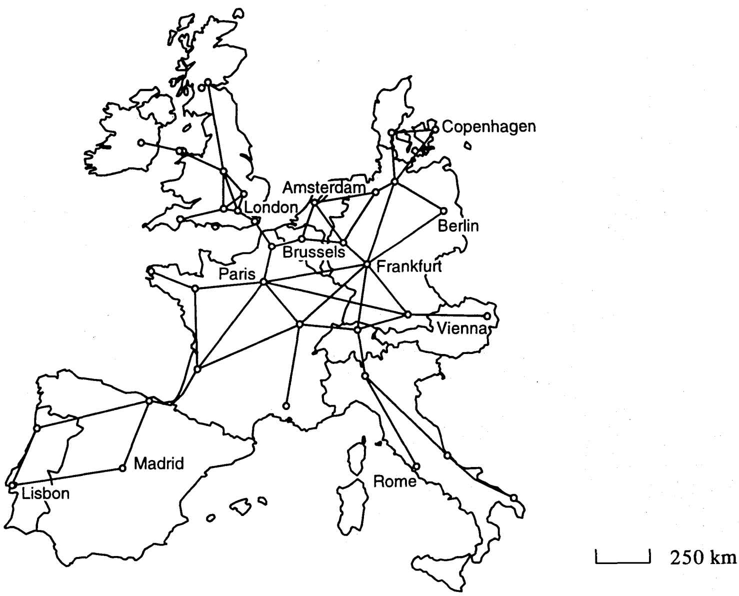
Figure 10. Time-space maps of the rail network in Germany: (a) 1993 and (b) 2010.

Western Europe

Figures 11 and 12 (see over) illustrate the impacts of rail infrastructure improvements on the time space of western Europe. The network was reduced to the base network of figure 11(a) used already in figures 3, 4, and 5. For this network travel times were collected from timetables and forecasts for different points in time (ACT Consultants et al, 1994; Fayman et al, 1994). The following infrastructure scenarios were considered:

(a) *Rail network 1991* In 1991 the European high-speed rail network consisted of only one link, the TGV between Paris and Lyon. All other parts of the network operated at lower speeds.

(b) *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 Mediterrané, 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.



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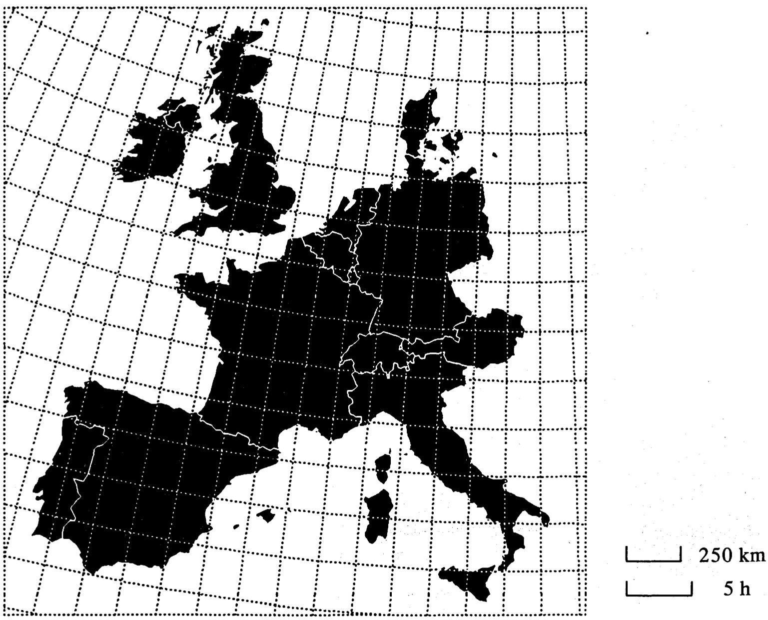


(b)

Figure 11. (a) Calibration network and (b) 60 km h^{-1} base map of western Europe.

The impacts of these scenarios on the time space of western Europe are presented in figure 12; figure 11(b) shows the base map as reference. The base map refers to an air-line speed of 60 km h^{-1} and has the same time scale as the following time-space maps.

Figure 12 shows that the impacts of the new high-speed rail lines are substantial. Even in 1991 [figure 12(a)], France was contracted by the first TGV between Paris and Lyon, whereas Spain and Portugal appear larger and Great Britain and Ireland

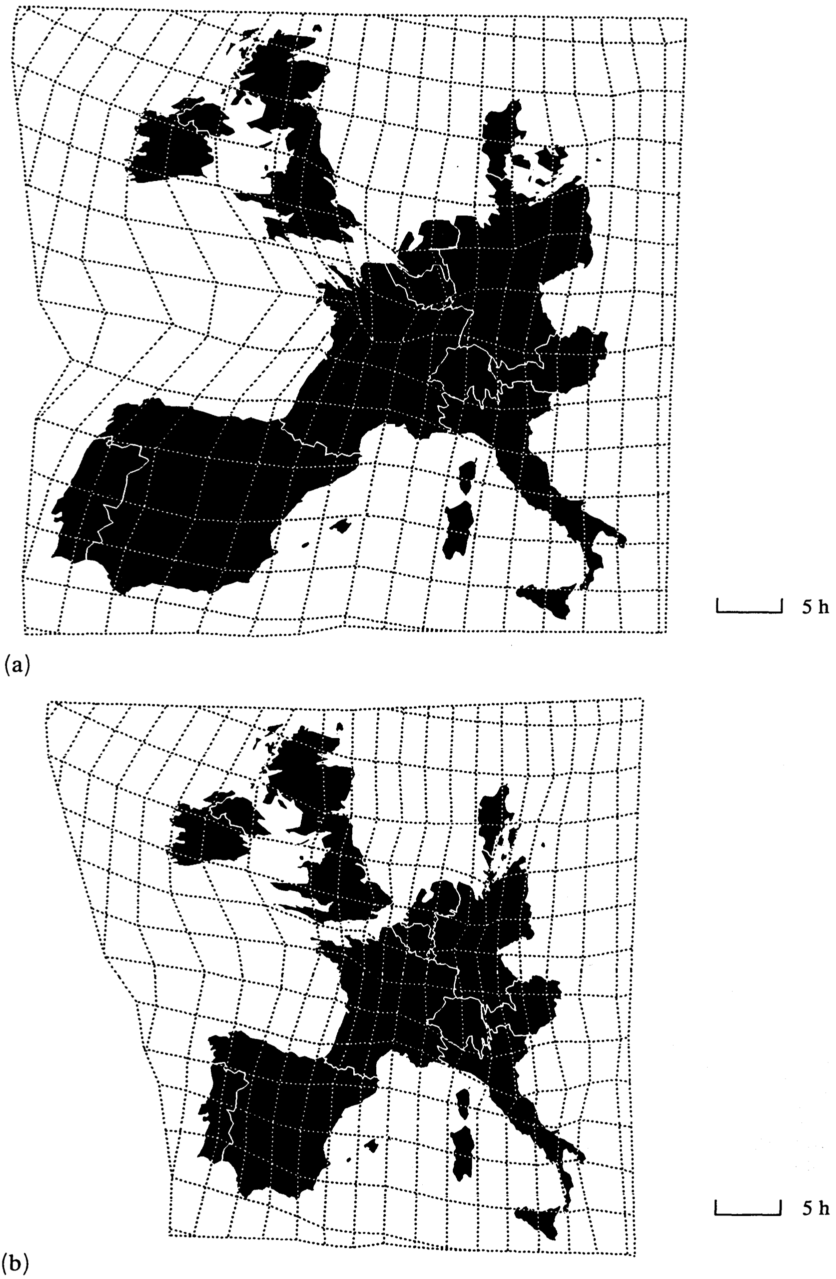


Figure 12. Time-space maps of the rail network in western Europe: (a) 1991 and (b) 2010.

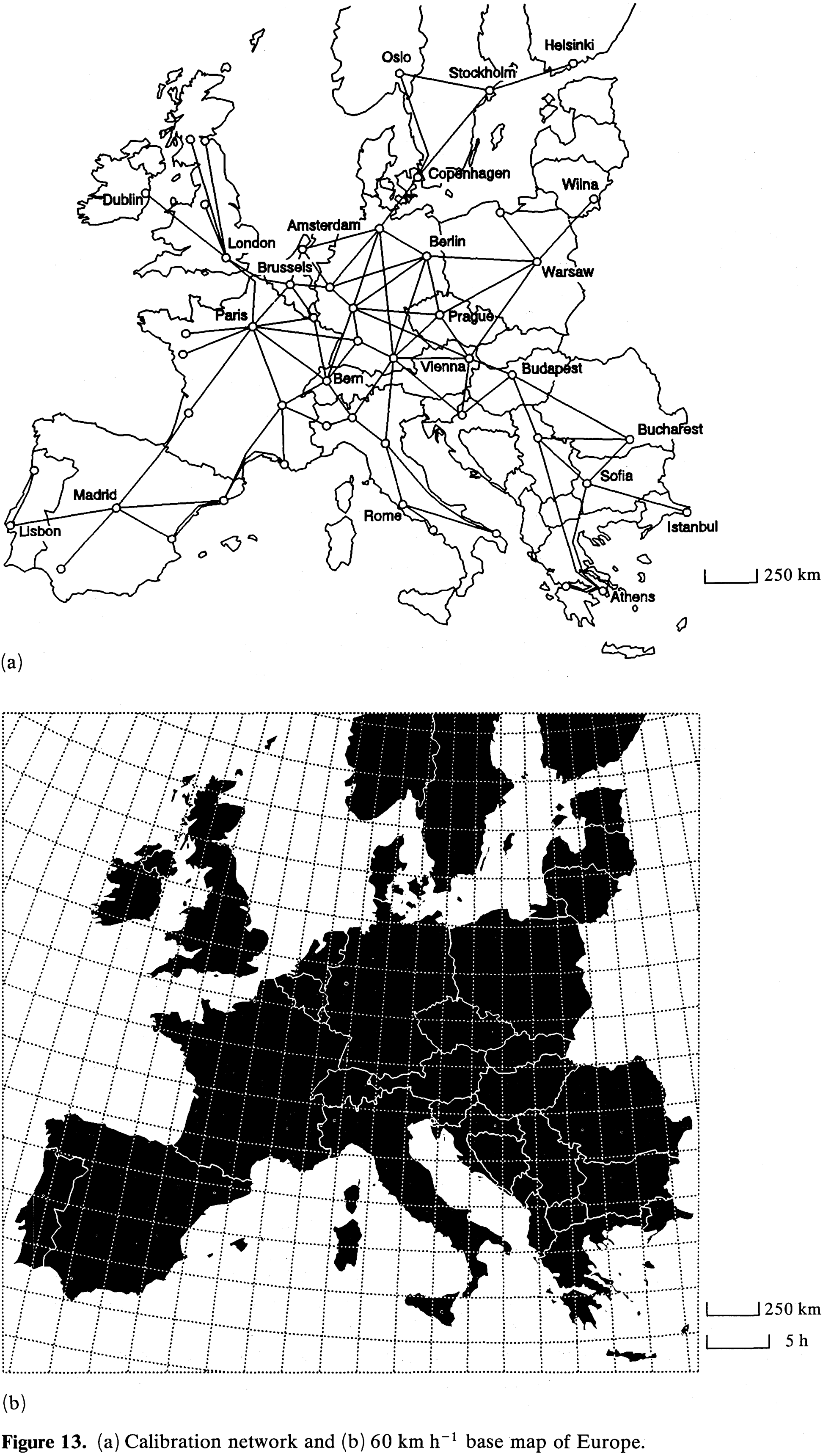


Figure 13. (a) Calibration network and (b) 60 km h^{-1} base map of Europe.

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 12(b)]: the continent has been reduced to half its original size. The southern parts of England are pulled towards 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. However, rail becomes the fastest surface transport mode in Europe (Spiekermann and Wegener, 1992).

Europe

Figures 13 and 14 show time-space maps of the whole of Europe (excluding Russia and the Ukraine). Figure 13 shows the calibration network and the 60 km h^{-1} base map. Compared with figure 11, the network is extended to eastern and northern Europe, but is also different in western Europe.

Figure 14 (see over) shows time-space maps of the rail network in Europe today and in the year 2010 as envisaged by the International Union of Railways (Walrave, 1993). It becomes obvious that the peripheral location of Ireland in western Europe (see figure 12) is marginal if eastern Europe is included. The poor quality of the rail network there leads to slow speeds and a large representation on the time-space map. This is particularly true for southeast Europe. In 2010 (if the rail network envisaged by the UIC exists by then) the continent will have shrunk dramatically in time-space. However, its shape will become much more similar to the physical map.

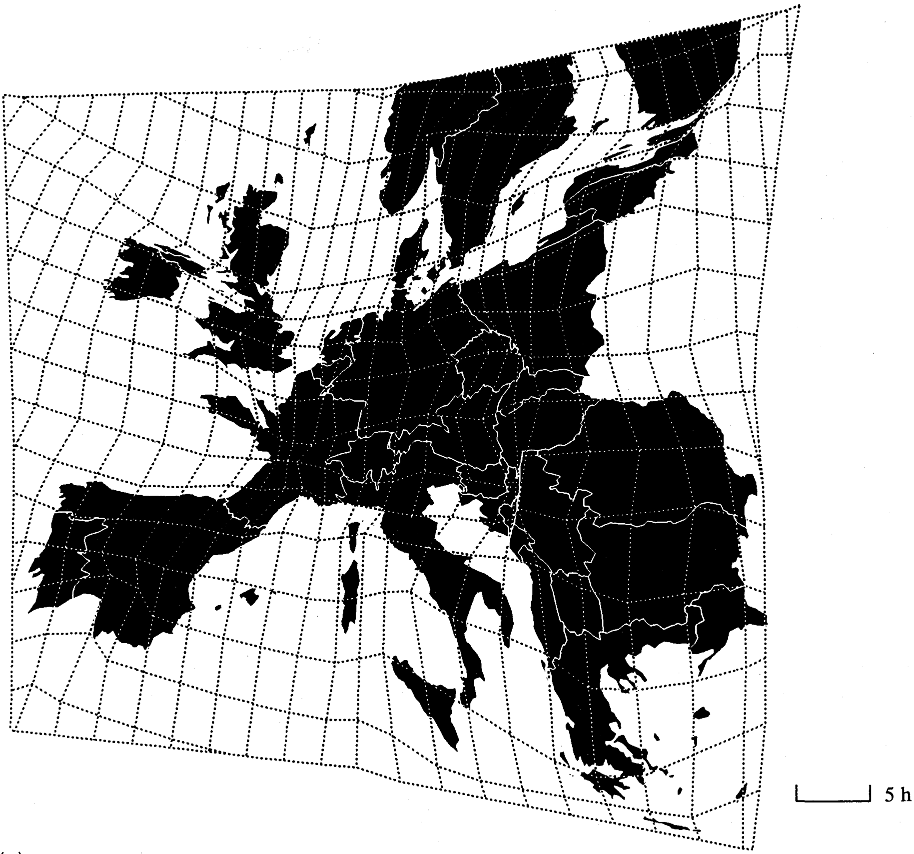
Conclusions

The method of creating time-space maps presented here avoids the disadvantages of current approaches by stepwise multidimensional scaling and interpolation with triangulation. By 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.

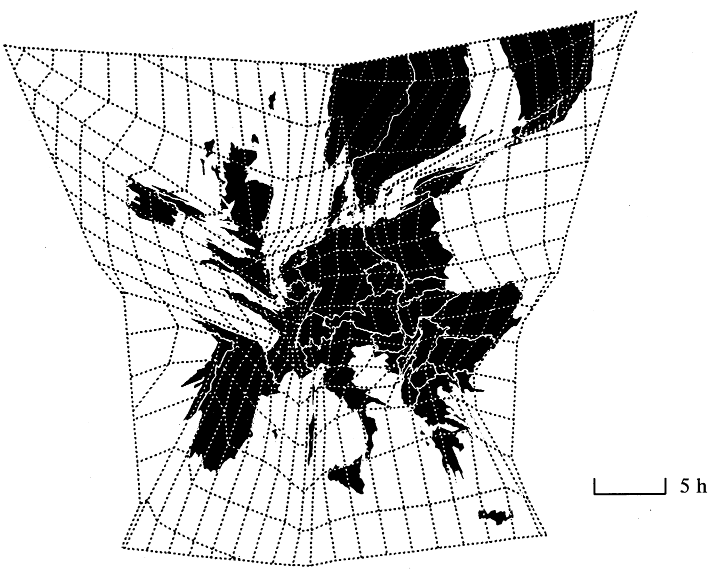
However, because there is no single best solution for a time-space map, the appearance and plausibility of the map depend on the skills of the map editor, who, by adding or deleting links of the calibration network or selecting a different origin node, can influence or even manipulate the results. A comparison between the two time-space maps of figure 7 or of the time-space maps of France with the shape of France within Europe in figures 12 and 14 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 such as France or Germany. However, high-speed infrastructure connects only important cities, but not the space in between them. This generalisation hides the fact 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.



(a)



(b)

Figure 14. Time–space maps of the rail network in Europe: (a) 1993 and (b) 2010.

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